Digitized by the Internet Archive
in 2022 with funding from
Kahle/Austin Foundation

https://archive.org/details/evolutionofearth0000lora

UNIVERSITY LIBRARY
UW-STEVENS POINT

THE EVOLUTION OF EARTH AND MAN

The Evolution of Earth and Man

By

LORANDE LOSS WOODRUFF
GEORGE HOWARD PARKER
RICHARD SWANN LULL
CHARLES SCHUCHERT
HARRY BURR FERRIS
JOSEPH BARRELL

ALBERT GALLOWAY KELLER
GEORGE GRANT MacCURDY
ELLSWORTH HUNTINGTON
JAMES ROWLAND ANGELL
EDWIN GRANT CONKLIN
WESLEY ROSWELL COE

Edited, with a Preface, by
GEORGE ALFRED BAITSELL
Professor of Biology in Yale University

NEW HAVEN
YALE UNIVERSITY PRESS
London : Humphrey Milford : Oxford University Press
MDCCCCXXIX

COPYRIGHT 1929 BY YALE UNIVERSITY PRESS

THE EVOLUTION OF THE EARTH AND ITS INHABITANTS

Copyright 1918 by Yale University Press

Published 1918
Reprinted 1919, 1920, 1922, 1923, 1924

THE EVOLUTION OF MAN

Copyright 1922 by Yale University Press

Published 1922
Reprinted 1922, 1923

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

THE various chapters in this book present, it is believed, an authoritative and comprehensive survey of the present state of our knowledge in a number of related fields, all of which are concerned, in the last analysis, with the question of the origin of the earth and life upon the earth, particularly with reference to man.

A considerable proportion of the material in this volume was originally given in two series of lectures at New Haven under the auspices of the Yale Chapter of the Society of the Sigma Xi — an honorary scientific society. Credit for the original idea should be given to Professor Richard Swann Lull who, as President of the Yale Chapter during the academic year 1916–1917, arranged for the first series of lectures by Professors Barrell, Schuchert, Woodruff, Lull, and Huntington, all of Yale University, under the general title of "The Evolution of the Earth and its Inhabitants." These lectures were later published (1918) by the Yale University Press under the same title and have had a wide distribution.

During the academic year 1921–1922 it became my duty as President of the Yale Chapter to arrange the scientific program for the society, and it was decided that the previous highly successful series of lectures could be continued with interest and scientific profit by another series in which specific consideration was given to the question of man's

25470

origin and development. Accordingly a number of authorities in the several fields concerned were invited to participate in a series of lectures under the general title of "The Evolution of Man." These lectures were given by President Angell and Professors Lull, Ferris, and Keller of Yale University, and by Professor Parker of Harvard University and by Professor Conklin of Princeton University. The material presented was also published (1922) by the Yale University Press under the same title and has met with a very cordial reception.

In considering at this time the question of again reprinting these volumes it was evident that the material presented was of permanent value and should continue to be available for distribution. Furthermore it seemed clear that the two volumes could with advantage be combined. It was also felt that, in order to make the survey complete, two other fields might well be included in the combined volume, namely, a consideration of man's cultural evolution and a consideration of the mechanism which brings about changes in living organisms from generation to generation and which is, therefore, in the final analysis, fundamental for evolutionary changes. The new chapter dealing with Cultural Evolution has been written by Professor MacCurdy of Yale University — an international authority on human origins. The new chapter on the Mechanism of Evolution has been written by Professor Coe of Yale University, who has long demonstrated his familiarity with this field both in the classroom and by the printed page.

Each of the chapters in the two original volumes has been submitted during the past few months to their respective authors for such revision as seemed necessary in order to bring the scientific material up to date. In this connection particular thanks are due to Professor C. R. Longwell for his kindness in revising the chapter on "The Origin of the Earth" by the late Professor Joseph Barrell, whose untimely death in 1919 was a severe loss to Geology and to science in general. As a result of this revision, extensive changes have been made in most of the chapters and some of them have been almost completely rewritten. Accordingly, it is believed, that the scientific knowledge, bearing upon the various problems under consideration, represents the most recent opinion of representative experts in the several fields covered. It is hoped that it will be found of interest and value.

As Editor of this volume, I wish to express my appreciation to all the contributing authors for their hearty cooperation and to the Yale University Press for the splendid attitude shown in all matters connected with its publication.

G. A. B.

Yale University,
Osborn Zoölogical Laboratory,
July, 1929.

CONTENTS

PAGE

Preface . . . . GEORGE ALFRED BAITSELL v

Chapter I. The Origin of the Earth . JOSEPH BARRELL 1

Chapter II. The Earth's Changing Surface and Climate . . . CHARLES SCHUCHERT 47

Chapter III. The Origin of Life LORANDE LOSS WOODRUFF 83

Chapter IV. The Pulse of Life . RICHARD SWANN LULL 110

Chapter V. The Antiquity of Man RICHARD SWANN LULL 148

Chapter VI. The Natural History of Man HARRY BURR FERRIS 187

Chapter VII. The Evolution of the Nervous System of Man GEORGE HOWARD PARKER 228

Chapter VIII. The Evolution of Intelligence JAMES ROWLAND ANGELL 251

Chapter IX. Cultural Evolution GEORGE GRANT MACCURDY 274

Chapter X. Societal Evolution ALBERT GALLOWAY KELLER 304

Chapter XI. Climate and the Evolution of Civilization ELLSWORTH HUNTINGTON 330

Chapter XII. The Trend of Evolution EDWIN GRANT CONKLIN 384

Chapter XIII. The Mechanism of Evolution WESLEY ROSWELL COE 417

Index 445

ILLUSTRATIONS

"We are part of a magnificent creation" From a drawing by O. E. Cesare . . . . *frontispiece*
Plate I. A. Nebulosity in the Pleiades. B. Spiral nebula in Ursa Major . . . . *facing page* 8
Figure 1. Diagram to illustrate tidal forces 14
Figure 2. Origin of a spiral nebula according to Chamberlin and Moulton 18
Plate II. The western and eastern hemispheres *facing page* 40
Figure 3. Diagram showing the times and probable extent of the more or less marked climatic changes in the geologic history of North America, and of its elevation into chains of mountains 54
Figure 4. Glacially striated diabase, made in early Permian time. South Africa . . . . . . *facing page* 56
Figure 5. Lower Cambrian quartzite, striated in early Permian time. South Australia . . . . *facing page* 56
Figure 6. Glacial bowlder beds on the upper Yangtse River, China . . . . *facing page* 58
Figure 7. Eroded exposure of the oldest known glacial deposits near Cobalt, Ontario . . *facing page* 60
Figure 8. Striated bowlder taken from the oldest known glacial deposits . . . . *facing page* 60
Figure 9. Generalized map of North America in Paleozoic time 64
Figure 10. The marine inundation in Pennsylvanian time . 68
Figure 11. Earlier and maximal phases of the Silurian flood 73
Figure 12. Great Middle Cretaceous transgression of the oceans over the lands 78
Figure 13. Diagram showing time and extent of the known

floods that have inundated North America since the close of the Proterozoic era 80
Figure 14. Diagram of the pulse of life 112
Figure 15. Squid capturing a fish 116
Figure 16. Fish forms . . . . *facing page* 116
Figure 17. Laurentian peneplain as seen from the south end of Lake Michikamau, Labrador . *facing page* 118
Figure 18. Lung-fish, breathing 122
Figure 19. African fringe-finned ganoid 123
Plate III. Cast of the oldest known fossil footprint from the Upper Devonian of Pennsylvania *facing page* 124
Figure 20. Development of the hind foot of a salamander . 125
Figure 21. Foot of a reptile 125
Figure 22. Restoration of the Permian stegocephalian . . 126
Figure 23. Diagram showing the relation of the extra-embryonal membranes . . . . . . *facing page* 128
Figure 24. Skull of cynodont reptile 129
Plate IV. Restorations of (A) the hypothetical proavian, and (B) the toothed bird, *Archaeornis* *facing page* 130
Figure 25. Tooth of a carnivorous dinosaur and jaw of a contemporary mammal . . . . *facing page* 132
Plate V. Restorations of archaic mammals *facing page* 134
Figure 26. Restoration of the creodont 136
Figure 27. Map showing the geographical distribution of the primates, living and extinct, and their indicated dispersal from Holarctica 139
Figure 28. Gorilla . . . . *facing page* 140
Figure 29. Gibbon . . . . *facing page* 142
Figure 30. Photograph of a submarine, twenty feet below the surface, taken from the aeroplane whose shadow is shown in the picture . . . . . *facing page* 144
Figure 31. Map to illustrate the broader lines of dispersal of the principal races of man 153

Plate VI. Models of the heads of prehistoric types of man *facing page* 160
Figure 32. Skull and face of the Java man 162
Figure 33. Skull and face of the Heidelberg man 164
Figure 34. Skull and face of the Piltdown man 169
Figure 35. Skeleton of Neandertal man compared with that of Crô-Magnon man 172
Plate VII. Fossil skulls of Neandertal man and Crô-Magnon man . . . . *facing page* 174
Figure 36. Skull and face of Neandertal man 174
Figure 37. Skull and face of Rhodesian man 177
Figure 38. Skull and face of Crô-Magnon man 180
Figure 39. Provisional phylogeny of man and the anthropoids 185
Figure 40. Diagram showing the fertilization of the ovum . 189
Figure 41. Diagrams of early human embryos . *facing page* 190
Figure 42. Human embryo of 1.54 mm. . . *facing page* 192
Figure 43. Human embryo of 4.2 mm. . . . *facing page* 192
Figure 44. Developing human brain . . . *facing page* 194
Figure 45. The pallium and cerebellum in the brains of various vertebrates . . . . . . *facing page* 196
Figure 46. The nerve cell 197
Figure 47. Spinal nerve . . . . *facing page* 198
Figure 48. Organs developing from the rudimentary alimentary canal 200
Figure 49. The human heart 202
Figure 50. Development of the face of a human embryo *facing page* 204
Figure 51. The human placenta . . . . . *facing page* 206
Figure 52. Embryos of the pig, rabbit, monkey, and man *facing page* 210
Figure 53. Changes in proportion during prenatal and postnatal growth 214

Figure 54. Growth curves for increase in weight and stature for both sexes 216
Figure 55. The caecum and vermiform appendix in various mammals 222
Figure 56. Supernumerary nipples of man 225
Figure 57. A pit at Bramford, England, exposing the plateau beds of Suffolk . . . . *facing page* 280
Figure 58. Chipped flint from the Chalk Plateau in Kent, England 280
Figure 59. Hand ax of flint. Chellean Epoch . *facing page* 284
Figure 60. Hand ax of flint. Acheulian Epoch *facing page* 286
Figure 61. Flint scrapers and points retouched on one face only; two bone compressors. Mousterian Epoch 287
Figure 62. Flint gravers. Aurignacian and Solutrean Epochs 290
Figure 63. Harpoons of reindoor horn. Upper Magdalenian Epoch 291
Figure 64. Metacarpals of the mammoth converted into human statuettes. Aurignacian Epoch 294
Figure 65. Bison incised on limestone. Magdalenian Epoch *facing page* 294
Figure 66. Reconstruction of pile-village home life during the Neolithic Period . . . . *facing page* 296
Figure 67. Bronze trumpet. Bronze Age 297
Figure 68. Pottery chiefly from the Marne. Epoch of La Téne (Iron Age) . . . . . . *facing page* 300
Figure 69. Climograph of France and Italy 350
Figure 70. Climograph of the northeastern United States . 349
Figure 71. Climograph of Southern California 351
Figure 72. Climograph of deaths among colored people in the eastern United States, 1912-1915. Non-contagious diseases 358
Figure 73. Climograph of deaths of white people in the east-

ern United States, 1912-1915. Non-contagious diseases 359
Figure 74. The distribution of human energy on the basis of climate 363
Figure 75. The distribution of civilization 363
Figure 76. Diagram of the chromosomes in a cell of *Drosophila* and in man 420
Figure 77. Diagram of the division of the genes in a chromosome 421
Figure 78. Portions of three pairs of chromosomes to indicate theoretical arrangement of genes 424
Figure 79. Division of the chromosomes in normal cell division 428
Figure 80. Reduction in the number of facets in the eye of *Drosophila* 433
Figure 81. Skeleton of forefoot of a normal cat and of a polydactylous cat 434
Figure 82. The foot of the domestic pig, showing a syndactylous mutation 435
Figure 83. Polydactyly in the hand of man 436

CHAPTER I

THE ORIGIN OF THE EARTH[1]

JOSEPH BARRELL[2]

LATE PROFESSOR OF STRUCTURAL GEOLOGY, YALE UNIVERSITY

INTRODUCTION

THE logic of all branches of science points to the existence of some system of evolution of the universe, its complete nature hidden in the vastnesses of time and space, but nevertheless developed in accordance with Nature's laws. The earth is one of the celestial host, its beginnings are bound up with that of other bodies. In the history written in the structure of the earth and in the relations of the earth to the planets, stars, and nebulæ lies concealed the story of its genesis. Two chief methods of approach, the geologic and astronomic, lead toward the solution of this fundamental problem.

The history of the earth is read in the rocks which have been thrust up by internal forces and beveled across by erosion. The nearer events are clearly recorded in the sequence and nature of the sedimentary rocks and their fossils. But the oldest formations have been folded, mashed, and crystallized out of all resemblance to their original nature, and intruded by molten masses now solidified into granite and other igneous rocks. Fossils, the time markers of geology, if once existent, have been destroyed, and, as in the dawn of human history, vast periods of time are dimly sensed through the disordered and illegible record. This crystallized and intricately distorted series of the oldest terrestrial rocks tells of an earth surface on which air and water played their parts, much as now. But it was a surface repeatedly overwhelmed by outpourings of basaltic lava on a vaster scale than those of later ages, and the crust was recurrently broken up and engulfed in the floods of rising granitic magmas. Here the geologic record begins, but the nature of its beginning points clearly to the existence of a prehistoric eon. At the farther bounds of this unrecorded time, forever hidden from direct observation, lies the origin of the earth.

---

[1] Some pages of the following article have been drawn from one by the writer entitled "Origin of the Solar System Under the Planetesimal Hypothesis," published as Chapter XXV in Pirsson and Schuchert's "Text-book of Geology," 1915. For permission to use this material grateful acknowledgment is made to the authors and publishers of that work.

[2] See note A, page 45.

But the mind of man will not be baffled. Since he may not see directly he will see by inference. Convergent lines of evidence derived from various fields of knowledge may be followed part way toward this goal, like those rays perceived through the telescope on the full moon near the margin of its visible hemisphere, which converge toward craters on the side of the moon that no eye shall ever see.

Leaving the geologic field of evidence, the problem of the origin of the earth may be approached from the astronomic side. The relationships of the earth to the stars and the planets are displayed in the depths of the heavens, and vestiges must there exist of the cosmic conditions which gave birth to our world and the other planets of our system. The forces of nature are found to obey the same laws as far as the telescope can penetrate. The spectroscope detects the familiar chemical elements in distant stars. These instruments give assurance of the unity of the cosmos, but the diversity of objects indicates various stages and various types of evolution. Which approaches nearest to that of our solar system? We must be content to study very much larger and therefore unlike systems, since from the distances of even the nearer stars the earth and her sister planets would be hopelessly invisible in the most powerful telescope. We cannot, then, follow into the planetary stage the evolution of other systems comparable to our own. Yet in nebulæ, in stars, and in the inherited motions and configurations of our planetary system are clues which pieced together lead up toward the origin of the earth.

The problem of the origin of the earth is within the domain of scientific investigation, but as yet the pictures which may be drawn are varied. The vague outlines shift and change but become clearer with the growth of knowledge. Where the solution of a problem is not yet definitive and certain, the method of multiple working hypotheses should be used. All facts and theories should be matched to these several hypotheses to determine which one of them shall be selected and modified, and which shall meet the fate of the unfit. At the present stage of investigation any one view should not be regarded as established beyond question, even though the assembled evidence seems strongly to support it. In a single presentation, however, all hypotheses cannot be equally treated and each investigator, while recognizing the existence of other hypotheses, may properly emphasize that one which seems to him most in accordance with the various categories of facts and more firmly established inferences.

The hypotheses of earth origin begin more especially in the astronomic field in the search for initial causes; they end in the geologic field where they dovetail into the known relations. The surviving hypothesis must give a sound explanation of those broader terrestrial conditions of atmosphere, hydrosphere, and lithosphere, of ocean basins and continental platforms, which had become established by the beginning of the geologic record. But, although much has been learned, it is still unsettled among geologists as to how far those fundamental conditions in early geologic times were different from those of the present. On the whole, the problem of the genesis of the earth appears to lie somewhat more in the field of the geologist than in that of the astronomer.

THE PLACE OF THE EARTH IN THE UNIVERSE

The earth, a member of the solar system. The earth is but one among the planets which together with the sun constitute the solar system. It is neither the largest nor the smallest, neither nearest to nor most remote from the sun.

The sun is a star and is but one among the millions of stars, and, though apparently so great as seen from the earth, is mediocre among them in size and brightness. The origin of the earth is obviously bound up with the origin of the other planets and all in the history of the sun. A presentation of the significant facts of magnitudes, motions, and distribution of these bodies, familiar though they are to most readers, should therefore precede the consideration of the genesis of the earth.

The planets visible to the unassisted eye are, besides the earth, five in number, distinguished by the ancients from the stars by their steady light and by their wanderings through the zodiacal path in the sky, wanderings produced as a result of the combined effect of their motions and that of the earth in nearly circular paths about the sun, their common center. The telescope has added to the number of planets two large ones, Uranus and Neptune, invisible to the naked eye because of their distance from sun and earth, and, in one zone of intermediate distance, a swarm of smaller bodies, the asteroids, better called planetoids. In size the planets sink to vanishing insignificance in comparison with the sun or any other star. Their distances from the sun and from each other are also almost infinitesimal in comparison with the distances which separate the stars. They shine by light reflected from the sun, and as all the planets and planetoids are attendant upon the sun, they form a common system, the solar system. The facts regarding their size, their distance from the sun, and the inclination and position of the planes of their orbits with respect to the orbit of the earth are tabulated as follows:

PRINCIPAL ELEMENTS OF THE SOLAR SYSTEM

Name		Diameter, miles	Density, water=1	Mean distance in millions of miles from the sun	Inclination of plane of orbit to earth's orbit
	Sun	866,400	1.39	....	7° 15′[1]
Minor planets	Mercury	3,030	?	36	7 00
	Venus	7,700	4.85	67	3 24
	Earth	7,918	5.58	93	0 00
	Moon	2,162	3.40	0.239[2]	5 09
	Mars	4,230	4.01	141	1 51
	Planetoids	0 to 485	?	200 to 400	0 to 34 42
Major planets	Jupiter	86,500	1.33	483	1 19
	Saturn	73,000	0.72	886	2 30
	Uranus	31,900	1.22	1,782	0 46
	Neptune	34,800	1.11	2,792	1 47

[1] Inclination of sun's equator to earth's orbit.

[2] Mean distance of moon from earth.

Notable Planetary Relations. That the orderly nature of this system implies some mode of evolution was seen by the framers of the nebular hypothesis. The more notable of these relations, following the summary by Young, are:

1. The orbits are all nearly circular.
2. They are nearly in one plane (excepting the cases of some of the little planetoids).
3. The revolution of all is in the same direction.
4. There is a curiously regular progression of distances from the sun (expressed by Bode's law, which, however, breaks down at Neptune). See foregoing table.

5. There is a rough progression of density, increasing both ways from Saturn, the least dense of all the planets in the system.

As regards the planets themselves, we have:

6. The plane of the planets' rotation, the plane of their equators, roughly coinciding with those of the orbits (probably excepting Uranus).

7. The direction of the rotation of the planets about their polar axes the same as that of their revolution in their orbits (excepting probably Uranus and Neptune).

8. The plane of orbital revolution of the satellites of each planet coinciding nearly with that of the planet's rotation, its equatorial plane.

9. The direction of the satellites' revolution in their orbits also coinciding with that of the planet's rotation about its axis, with exceptions in the case of the ninth satellite of Saturn and probably the seventh of Jupiter.

10. The largest planets rotating most swiftly.

The sun, a member of the stellar system. The sun, as has been stated, is but a star and a member of the stellar system. What are the orders of magnitude in number, in size, in distance, in speed, in duration among these countless orbs, and how do these relations enter into the problem of the origin of the earth as one of that retinue of planets which attend upon the sun?

The luminous stars of our system are estimated to be more than a hundred million in number. The number of the dark stars is unknown. Giving no ray of light to reveal their existence, they may for all we know be as numerous or more numerous than those in the radiant stages of their existence. The few stars whose sizes are known range in diameter from somewhat below a million to upward of ten million miles and more.

Many of the stars are in reality double or multiple stars, consisting of companions so close that the two or more appear as one star to the naked eye, or even under the highest power of the telescope, the evidence of their composite nature being revealed only through the analysis of their light by the spectroscope. These double stars revolve swiftly about each other, but such internal motions must be sharply distinguished in thought from the streaming or drifting of the stars as parts of the great stellar system. Relatively to the sun they are found to move through space with speeds averaging between 10 and 30 miles per second, but ranging from less than 10 to more than 200 miles per second. They do not move, however, singly and in closed orbits, but rather in broadly scattered groups whose paths are almost straight lines. These courses of the stars must slowly curve under the aggregate attraction of the millions of stars, but can never return into themselves. The paths of groups of stars intersect other groups and are to some extent interwoven among themselves. These groups have been found to be integrated into two greater groups intermeshed among each other and forming two great star streams whose average motions are in opposite directions. With the passage of millions of years, the stars thus continually enter into new relations and build new configurations in the skies: a myriad host of stellar fireflies, the living and the dead, streaming through space hundreds of millions of miles per year.

Although the stars are so great in number, their distances from each other average tens of millions of millions of miles, those in our part of the stellar system averaging between sixty and eighty trillions. The star nearest to the sun, α Centauri, happens, however, to be at a lesser distance of about twenty-six trillions of miles.

To bring down the dimensions of the universe to finite comprehension, we must divide the scale of nature by a thousand million. Then the earth would be represented by a pebble half an inch in diameter, circling once a year about a sun 4.5 feet in diameter, at a distance of 500 feet. The nearest star, α Centauri, would on this same scale be seen as two spheres revolving about each other at a distance apart equal to 2 miles, and each comparable in size to the sun. This double star would be situated at a distance of about 25,000 miles from our planetary system with its sun, but the other stars in this part of the stellar system would be separated from each other on the average by more than twice this distance. The Galaxy, or Milky Way, is the cloud-like zone of faint stars which extends as a belt around the sky. The stars in it appear faint and close together because of their remoteness. They seem to constitute the outer zone of our stellar system, and its dimensions are only vaguely known. On this diminutive scale the Milky Way might be found to be encompassed by a circle of a hundred million miles diameter, or it might be more or less.

The nebulæ. All hypotheses of earth origin derive the planets and the sun from an antecedent nebulous or meteoritic state. The cloudy patches of light known as nebulæ, which are revealed especially by stellar photography, are, however, of several very different natures and it is a vital question as to which, if any, of these types, could have given birth to our planetary system.

First are the irregular nebulæ, diffuse clouds of luminous matter, pervading whole groups of stars as in Orion and the Pleiades, shown in Plate I, A, denser about certain stars, but nevertheless enormously attenuated. This kind of nebulosity is associated with certain regions of the Milky Way. From the characteristics of their spectra, the stars in such nebulæ are regarded as young stars and the nebulous matter may represent the remains of an antecedent stage.

The planetary nebulæ are a distinct type, comparatively few in number, and also found associated with the Milky Way. They show in the telescope faint, greenish, circular discs from which they derive their name rather than from any known

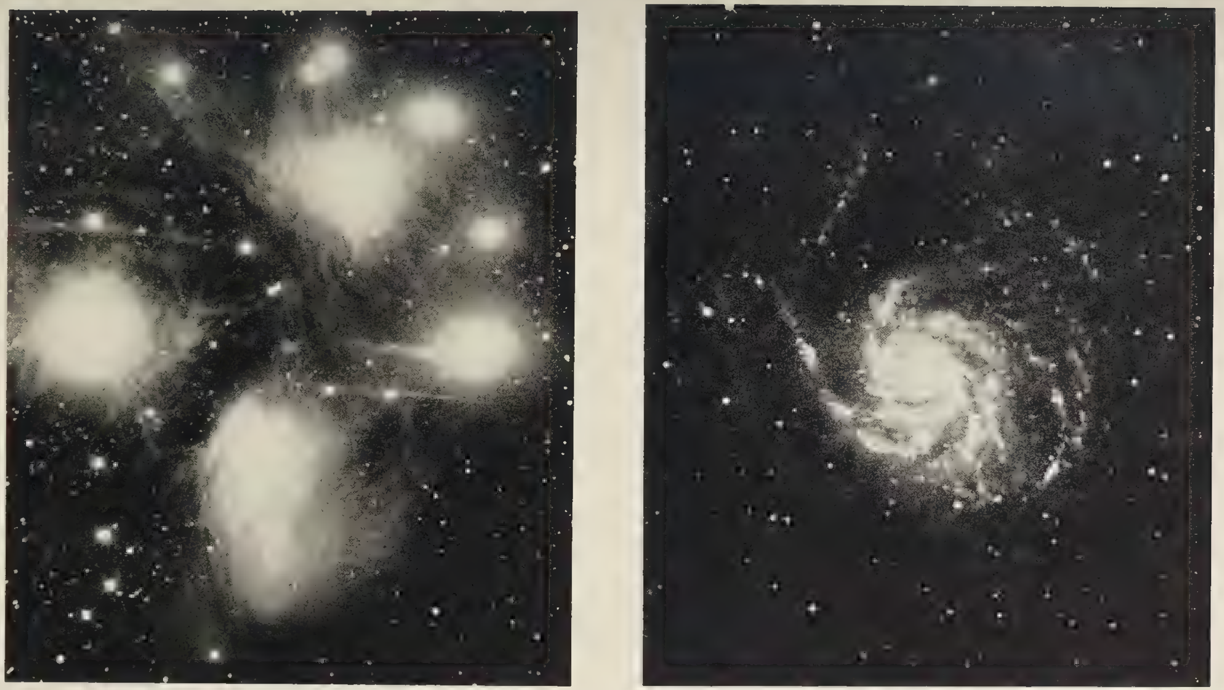


Fig. A

Fig. B

Plate I.—A, Nebulosity in the Pleiades; B, Spiral nebula in Ursa Major. Photographs supplied by Yerkes Observatory.

relationships to planetary systems. They seem to be related in their origin to New Stars and these in turn are thought to be produced by stars sweeping through clouds of meteoric or gaseous matter and attaining temporarily, from the swift impacts, an enormous brilliancy. The impact is so superficial, however, that the extreme brilliance is usually lost in a few days or weeks, and the star subsides through a stage like a planetary nebula into a peculiar type of star known as the Wolf-Rayet stars. The origin of the true planetary nebulæ has not, however, been observed, as they appear to possess a longer life than those which have originated in the past few centuries from new stars.

The ring nebulæ are few and special, having the form of a vortex ring.

The stellar nebulæ form another small group which look in the telescope like hazy stars.

By far the greatest number of the nebulæ are classified as spiral nebulæ, several hundred thousand of which have been made known by photography in connection with the greater telescopes. Their actual number must be far greater. These objects, unlike the other forms of nebulæ, avoid the Milky Way, and are scattered over regions where the stars are more widely spaced. They are very remote, and at least some of them are beyond our stellar system. This implies enormous magnitude. It seems probable that in general they possess high internal velocities, which implies in turn enormous masses to generate such velocities. These nebulæ possess spectra similar to those of stars rather than, like the other types of nebulæ, spectra of diffuse clouds of gas. Some astronomers look upon them, therefore, as possibly systems of stars rather than true nebulæ; systems so remote as to give the appearance of faint cloud-like spirals, even when viewed under the highest powers of the telescope. A typical spiral nebula is shown in Plate I, B.

HYPOTHESIS OF PLANETS DERIVED FROM A PRIMAL NEBULA

The original hypothesis of Kant and Laplace. In 1754 and 1755 Immanuel Kant, the philosopher, published the most remarkable papers which had appeared up to that time upon the evolution of the solar system. He conceived matter to have been originally diffused and cold. From a position of rest it began to converge under the influence of gravitation and gave rise to the sun. He held that in some manner the matter in converging acquired a movement of rotation. Certain nuclei grew up independently from the center and gave rise to the planets and satellites. In 1785 he developed the idea that the contraction of the sun's mass would develop its heat, a view elaborated by Helmholtz in 1854. Thus Kant sought, and with some measure of success, to evolve the present state of the universe from the simplest condition by means of mechanical laws alone.

In 1796 Laplace, one of the most eminent of French astronomers, published a general work on astronomy, and in a short note at the end of the appendix proposed a theory of the origin of the solar system which shortly became widely known as the nebular hypothesis. He was evidently unaware of Kant's work published forty-one years previously. Laplace is most noted for his mathematical work on celestial mechanics, yet he did not develop his hypothesis along such lines and apparently did not attach much importance to it. Nevertheless, it became the dominant idea in cosmic evolution throughout the next century.

Laplace postulated an original nebula as a very hot, gaseous mass extending beyond the orbit of the farthest planet and possessing a uniform rotation throughout, as if it were a solid body. Its size was the result of a balance between expansion from its heat and contraction from its gravitation. As it lost heat it contracted and, with the same energy of rotation that it possessed before, necessarily revolved on its axis in a shorter time. At last a stage was reached where, in the equatorial belt, centrifugal force balanced gravitation and the matter subjected to this balance of forces could sink in no further. It is thought to have existed as a ring, left behind by the condensing mass. The ring, however, was unstable; it broke up and gathered into one body. During the further shrinking of the main mass other rings were in turn abandoned. Each gathered into a subordinate nebula, passed through an independent evolution, and the whole gave rise to the system of planets and their satellites.

Modifications of the nebular hypothesis. During the first half of the nineteenth century the nebular hypothesis was accepted by astronomers almost without question, but during the second half many serious dynamical objections were developed and a process of modification began, until now not much remains of the original conception of Laplace. A rather full statement of the hypothesis and the objections to it has been given recently by Campbell.[3] A briefer summary and a citation of but a few of the modifications in the general concept must here suffice.

George Darwin, Lockyer, Faye, Fouché, Poincaré, and others have taken part in this work, and in the opinion of these mathematicians and astronomers the framework of the resulting structure is still sound, though subject of course to further modification as knowledge increases. It was shown that the original nebula need not have been hot, but, as perceived by Kant, would develop heat from its self-condensation. A loose swarm of cold meteorites would suffice as well as an original gas for the initial state. The mass could never have revolved as a unit body, as if it were a solid. On the contrary, the inner parts would be condensed and revolve fast while the outer parts were still diffuse and revolved slowly. The mode suggested by Laplace for the separation of the rings is also dynamically very unsatisfactory. Moulton has shown that the growth of the planets and the development of rotation in the same direction as their orbital motion could be much better attained from an initial state in which the component particles revolved in the same plane but independently and in highly elliptic orbits about the central nucleus. This is a wide departure from the idea of a circular ring revolving as a unit body.

---

[3] Campbell, W. W., "The Evolution of the Stars and the Formation of the Earth." *Scientific Monthly,* vol. 1, 1915, pp. 189-194.

Still more fundamental objections, emphasized by Chamberlin and Moulton, are found in certain of the existing dynamical relations of the solar system. It would be expected that in condensation the central mass would continually abandon matter from its equatorial zone, the inner planets would presumably have possessed the greater masses, and the final sun would now show a high speed of rotation, giving an equatorial diameter far greater than the polar. Such expectations are contrary to the facts. The sun revolves so slowly on its axis, once in twenty-five days, that it has no measurable equatorial bulge. In other words, centrifugal force is negligible in the sun. Furthermore, the equatorial plane of the sun, instead of lying precisely in the mean plane of the planets' orbits, is inclined seven degrees to such a mean plane.

A hypothesis to gain scientific credence must emerge successfully from the test of observed facts and mathematical theory. The nebular hypothesis has not done so. It is on the defensive and has lost standing during the past generation. Some students are still loath to abandon it entirely, since it has the advantage of simplicity in that satellites, planets, and sun are explained as the products of a single process, convergence in a rotating nebula. But nature is often found to be complex in her operations, so that this advantage is of doubtful weight.

HYPOTHESIS OF PLANETS DERIVED FROM A SMALL SECONDARY NEBULA

Distinctive features of the planetesimal hypothesis. The recent planetesimal hypothesis of Chamberlin and Moulton postulates the sun already in existence from the ingathering of a primal nebula. It was at some later stage disrupted through the tidal forces produced by the close approach and passage of another star. The result was a secondary nebula, but one essentially unlike the primary. The secondary nebula was developed in a plane and initially possessed a spiral form with the sun at its center. All of its parts moved with freedom and independence in elliptic orbits, a point of difference from the Laplacian hypothesis. The nebula contained only a minute fraction of the solar matter, but was endowed by the passing star with a great rotational energy, so that, although so insignificant in mass, the planetary matter dominates enormously over the sun in the moment of momentum of the whole system. Thus the planetesimal hypothesis is a bold and frank abandonment of the terms of the original or nebular theory. It is too early as yet to predict what will be the ultimate fate of this hypothesis of a secondary, and, in a measure, an accidental origin of the planets, but, as expounded by its originators, it must be regarded as dynamically more satisfactory than the present form of the hypothesis of primary origin. The essential features will, therefore, be presented as the more probable preliminary steps in the genesis of the earth.

Forces of tidal disruption. The power of stars to disrupt each other without coming into actual contact, merely through relatively close approach, must be understood, as it is the basis of the planetesimal hypothesis.

The sun and moon raise terrestrial tides by virtue of the pull of gravity and thus modify that spheroidal form of the earth which is given by its own gravity and the centrifugal force of its revolution. Suppose, in other examples of heavenly bodies, the tidal pull to be many times stronger, the self-gravitative cohesion to be many times weaker. A limit will be reached at which the body may be pulled to pieces. This phenomenon, which has been actually observed in the case of comets passing close to the sun, has been called tidal disruption.

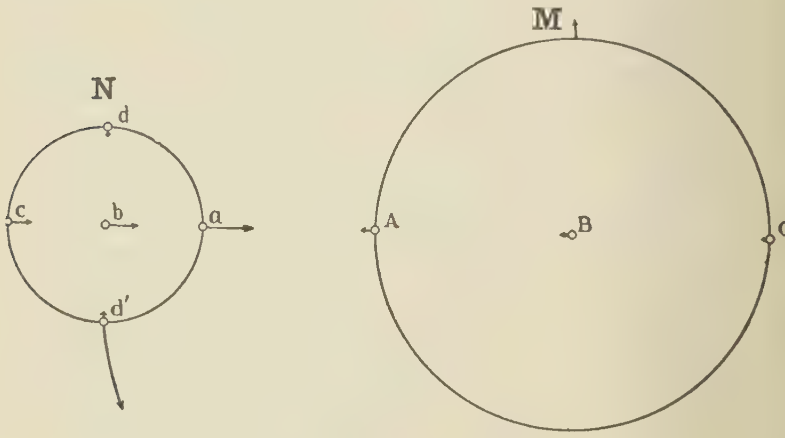


Fig. 1.—Diagram to illustrate tidal forces.

Let M and N in Figure 1 be two bodies passing each other in space, and consider the action of the larger on the smaller. According to Newton's law, the bodies attract each other directly as their masses and inversely as the square of their distances, causing them to swing toward each other while passing by, but soon losing influence as they separate in their journeys through space. Consider three particles, *a, b, c,* on the line of attraction, taking them as separate parts of the smaller body. But *a* is nearer to M than is *b,* and *b* is nearer than *c.* Therefore if we represent the relative attractions by lines, these lines will correspond to the distances which the particles would move in a given time if free to obey the attraction of the other body. The line at *a* is longer than that at *b* and the latter is longer than that at *c*. If N was not bound together by its own gravity or rigidity, *a, b,* and *c* would therefore drift apart and fan out while passing M. Consider that rigidity is negligible, as in a fluid globe; then, if *a* minus *b,* or *b* minus *c* are quantities which become greater than the self-gravitative force of N holding together *a* and *c,* the unity of the body becomes destroyed. The problem, however, is not quite so simple, since the influence of all other points in N must also be considered.

As the nearer part of the body is pulled from the center, and as the center is pulled from the farther side, there will, further, be two simultaneous tides of approximately equal height, but on opposite sides of the distorted body. They tend to be always on the line joining the two bodies. Thus, on the earth there are two tides on opposite sides, but the revolution of the earth on its axis, like a car wheel under two opposite brake-shoes, gives an apparent effect, to one on the surface of the earth, of a revolution of the tidal wave. As a result of the equal tides at opposite ends of a diameter there are, on any part of the ocean, two high tides in twenty-four hours.

Mode of tidal disruption in stars. A star is characterized by its enormous size and mass and by the possession of a gaseous constitution. The diameter and density are dependent upon the balance at every point between the tremendous expansive forces of internal heat and the equally great compressive forces due to its own gravity. If it contracts, then its surface and each component shell below comes nearer to the center, the effect of gravity upon any shell accordingly increases inversely as the square of the new radius, and a higher internal temperature becomes necessary to balance the higher gravitative force. From this there results the paradox known as Lane's law,—that so long as a body maintains a gaseous constitution its temperature must rise as it contracts, even though at the same time it is radiating heat. The temperature of the interior must furthermore be higher than the temperature of the surface, because of the greater compression with depth, as is illustrated in the different strata of the terrestrial atmosphere. In those convective or slow boiling movements which are necessary in the sun and other stars in order that they should be able to maintain their surface radiation, there is then a constant liberation of energy from the depths and a system of balanced motion which if disturbed could lead in any star to an explosive blowing out of material from it on an enormous scale.

The tide-generating force varies directly with the mass of the disturbing body and also with the radius of the body disturbed. It varies approximately inversely with the cube of the distance between the centers. The deforming force is, furthermore, greatest in the interior because the tidal forces acting on the zone at right angles to the line of attraction have a component which tends to squeeze in the points *d, d′* of Figure 1 toward the center. The gravitative control is accordingly weakened along the line *a, b, c,* and is strengthened in the directions at right angles. Now apply this principle to the gaseous balanced nature of a star, and it is seen that the expansion in the line *a, b, c* is no longer exactly balanced by the gravitative compression, and the unbalancing is greatest in the center, where also is the region of highest compression and highest temperature. The effect is as if one squeezed a syringe bulb with orifices for exit at both ends, a bulb, however, like an air rifle, filled with gas compressed to an explosive degree.

Tidal disruption of the ancestral sun. The sun is occasionally observed to shoot out streams of gas, known as solar prominences, to heights of nearly 300,000 miles, and at velocities ranging up to 300 miles per second. Such phenomena indicate the enormous elastic and explosive energy resident in the sun's interior, an expansive potency held in restraint by the equally prodigious power of the sun's gravity.

Supposing then that the ancestral sun was subjected to tidal disruption by the approach of another and possibly much more massive star, it remains to be seen how the nebula resulting from tidal disruption can become the embryo of an orderly planetary system. If the matter were shot out from great depths in the sun by its normal expansive forces plus the tidal forces, the velocity of departure might rise high above the observed velocities of 300 miles per second. If 400 miles or more, it would be above the "critical velocity" of the sun. The gravitative attraction of the latter could then never reclaim that matter, because the decrease in the outward velocity due to the solar attraction would never bring the velocity down to zero, and could therefore never reverse the motion of the escaping matter and bring it back to the sun.

It is doubtful if the sun could have drawn back to itself material expelled with a velocity of even 300 miles per second, for the passing star, by lowering the gravitative power of the sun on the line passing through the two, would temporarily decrease on that line the critical velocity. In other words, it would help to drag matter away from the sun, even though that matter could not catch up to the passing star, but would be left wandering in interstellar space, forming possibly cometary and meteoric material for other systems. But some, or possibly all, of the matter of the exploded sun may have had lesser velocities of escape and would consequently remain within its gravitative control. In so far as it was not deflected sideways by some extraneous force, it would fall back on the surface of the sun as the water of a geyser falls back into its pool. But the gravitative pull of the passing star would serve as such an extraneous force, analogous to the wind which blows part of the geyser water, as it rises and falls, to one side of the basin. The matter shot out toward the passing star would be attracted sideways after it as the star receded into space. On falling back toward the sun it would consequently pass to one side and elliptical orbits of the separate particles would become established. The material shot out in the reverse direction, from the opposite side of the sun, would meet much the same conditions except that the sidewise pull of the passing star would be less on it than on the sun. It is seen that the lateral or deflecting force acting on both arms of the nebula would be due to the difference between the pull of the passing star on each arm and on the central body. The initial spiral arms do not then represent the path along which the material was shot out, but mark the rotation around the central body or sun, both of the axis of expulsion during the passing of the star and of the matter after it is expelled, as shown in Figure 2.[4]

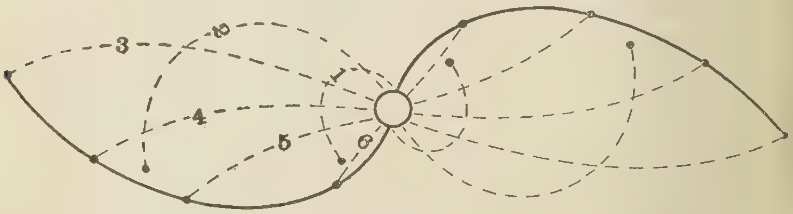


Fig. 2.—Origin of a spiral nebula according to Chamberlin and Moulton.

The nebula would be developed in a plane. That plane is established by the hyperbolic orbit of the passing star with the sun at the focus of the orbit. The new system would thus show in its nature features imposed by both its parents.

From such a nebulous fiery birth Moulton especially has shown how, in accordance with the laws of celestial mechanics, a planetary system could result.

The matter which has converged into the planets would be that residue of the solar tidal disruption which did not pass beyond gravitative control and did not fall back into the body of the sun. This residue is only a very small fraction of the sun's mass. It would appear probable, however, that the solar disruption was very great in order to give an axial revolution to the reaggregated matter forming the present sun, so that its equator should be, as observed, only seven degrees from the mean plane of all of the planetary orbits. The present revolution of the sun is probably due then to the whirl produced during tidal disruption and not to an axial rotation belonging to the sun before the event took place.

---

[4] See note B, page 45.

This brings us to the final stage in the evolution of the planets according to the planetesimal hypothesis. In the arms of the nebula were knots or nuclei of matter constituting the cores of the planets. Four small knots, the earth-moon knot being a double one,[5] represented the beginnings of the four small inner planets (see table, page 5). In the zone of the planetoids there was, however, no dominating nucleus, and they have therefore remained to this day largely in the planetesimal state. Four greater nuclei beyond were the beginnings of the major planets. Smaller nuclei associated with the larger marked the presence of satellites.

The orbits of the planetary nuclei and of the scattered planetesimal swarm were highly eccentric, having the form of a tangle of ellipses of all forms and sizes but lying in nearly a common plane and with a common direction of revolution about the central body. Collisions would inevitably occur at the crossing of the paths in the course of numberless revolutions and the nuclei would have sufficient mass and consequent gravitative power to retain the matter colliding with them. In this way, each planet would in the course of time clear up an orbital zone, and these zones, because of the eccentricities of the orbits of the component particles, overlapped each other with the exception of a region between Mars and Jupiter. But Moulton has shown that in such planetary growth by accretion, an axial revolution would arise in the

[5] See note C, page 45.

same direction as the orbital revolution, and that the incorporation of all the planetesimals would cause the eccentricities to cancel out, giving to the whole mass a nearly circular instead of a highly elliptical orbit. This would lead us to believe that the original nucleus was but a small part of the completed planet, so that its original ellipticity of orbit was submerged beneath the average influence of the added masses.

Outstanding difficulties of the planetesimal hypothesis. The disruption or spiral nebula hypothesis explains the features of the solar system more successfully than the older nebular hypothesis has thus far been able to do, but there are difficulties still remaining, though these may perhaps be the result of special conditions.

The most striking departure of the real system from that expectation deduced from the hypothesis is found in the rotation of the sun. The passing of a star able to drag matter from the sun to the distance of the planet Neptune would be expected to lead to an enormous tidal distortion of the sun's mass. This great tidal wave would involve a lifting and revolution about the sun, tending to give it a certain energy of rotation. A very little stronger action and the sun would in fact have been literally pulled to pieces and its matter scattered beyond its gravitative control. It is possible that it may in this way have lost a part of its mass. Considerable quantities of the expelled matter should have fallen back obliquely in the sun and tended further to increase its velocity of rotation. The path of the approaching star could have had no relation to the previous equatorial plane of the sun. The probabilities would consequently be that the final rotation would be a resultant between the older and newer forces and lie in an intermediate plane at a considerable angle to the plane of the planets' orbits. Now, as a matter of fact, the sun, as has been previously noted, revolves but once in twenty-five days and its equator is inclined but seven degrees to the mean plane of the planets' orbits. To explain this, Chamberlin supposes that the sun had originally a rotation in a plane not greatly different from that in which the passing star approached, but rotated in the opposite direction. The whirl given to the solar mass by the tidal disruption is assumed to have been a little greater than its initial rotation, but, being in the opposite direction, the resultant was at a slow speed and yet nearly in the plane of the planetary orbits.[6] Campbell points out that the chances are highly against such a special arrangement. If in a number of solar systems such an arrangement prevailed, it would constitute a conclusive proof against the hypothesis, but in the one example the exceptional combination may have occurred and it cannot be urged as a disproof.[7]

Turning to another aspect of the hypothesis, the innumerable spiral nebulæ of the heavens, although good illustrations of the initial hypothetical *form* of the solar planetary system, do not appear to be stages in a similar evolution in the way that Chamberlin and Moulton have conceived them to be. They are, as previously stated, of a much vaster order of magnitude, they avoid the region where the stars are clustered, are at remote stellar distances, and by their very number show a notable duration of their form. On the other hand, the postulated originally spiral form of the solar nebula would have been evanescent. Within a century from the time of origin all except the outer nuclei would have completed many revolutions about the sun. But the different periodic times of the nuclei would in a few revolutions have caused the initial spiral form to disappear. It would become wound up and further blended together owing to the high ellipticities of the constituent orbits.[8]

---

[6] Chamberlin, T. C., "The Origin of the Earth," 1916, pp. 130-132.

[7] Campbell, W. W., "The Evolution of the Stars and the Formation of the Earth." *Scientific Monthly*, vol. 1, 1915, p. 241.

[8] See note D, page 45.

The temporary dispersal of the solar mass would lead to an enormous increase in its radiant energy. The planetesimal matter would as a consequence of its dispersion and increased radiating surface cool with great rapidity, except in the nuclei of masses, and cease to be self-luminous, the smaller particles almost immediately becoming cold except as they were heated by the larger and profoundly disturbed solar mass.

The new stars which have been observed are not regarded as of this nature since they are not expanded into a spiral. In fact, as previously mentioned, no examples are known which serve as illustrations, in the terms of this hypothesis, of the birth stage of planetary systems. This lack of examples may be connected with the small scale as well as the temporary character of such a nebula. The whole solar system, extending to the orbit of Neptune, would subtend slightly less than half a minute of arc as seen from the nearest star. The average star is hundreds of times farther away and at the greater distances a nebula of this order would not betray its existence by its form but only by the temporary great increase in radiance at the time of its birth.

Chances of close approach. Whether the chance is great or small of a planetary system being generated from any particular star by tidal disruption cannot be used as an argument for or against this hypothesis unless it were known what proportion of the stars possessed planetary systems. But that knowledge is hopelessly concealed from us in the depths of space, since such a system as ours after its temporary initial brilliance would, as shown, be invisible in the most powerful telescopes even if it existed about the nearest star.

It is not known how near an approach would be necessary to generate such a solar system; but the chances of close approach must be very small for any particular star. The motion at any instant of any individual star is the result of its motion inherited from the past plus the attractions of all the matter in the universe pulling upon it in the present. If two bodies without previous motion were to be attracted toward each other, and were able to ignore the gravitative pull of all other bodies, they would move in a straight line toward each other's centers with ever increasing velocity until collision would result. But the least inherited motion in any other direction, or the least deflecting pull upon one of them more than upon the other by other bodies would prevent to that degree a central collision, or in almost all cases any collision whatever. Now the velocities of the stars through space at great distances from each other are so great that individual stars can have almost no attractive influence upon each other. They must move in nearly straight lines past each other unless they happen to pass within a thousandth part of their average distance. It is seen then that the chances of close approach depend primarily upon the accidental crossing of their paths and only secondarily upon their mutually attracting each other. For this reason the chance of actual collisions may be regarded as negligible, even considering the vast number of stars. Approach sufficiently near to generate strong tidal forces would, however, have occurred during their long lifetimes as radiant bodies to a considerable number out of the hundred million or more of stars which are known to exist in the stellar system, but for any one individual star, where the spacing is of the magnitude existing in our part of the stellar system, the chance of such approach even in a billion years would be very small. In fact, it has been estimated as only one chance in 1,800 in that time. It is possible, however, that this happened once to our star, that is, to our sun of that time, in the distant past and from that disruptive tidal force was born our system of planets. If such an event was in fact a necessary antecedent condition, fortunate indeed has been our planetary fate, for not only did this happen so early in the sun's career that its radiant energy has been able to endure through all the ages needed for organic evolution, but the spacing of the stars is so wide and the chance of approach so rare that no other of them has since advanced sufficiently near to throw this system into disorder, or to disrupt and sweep away the earth and its sister planets as a wasted effort, and start the re-creation of a new heaven and a new earth.

Hypothesis of Earth-Growth by Slow Accretion of Planetesimals

Under the terms of either nebular or planetesimal hypothesis a scattered state of the planetary material is implied as a stage antecedent to the origin of the planets. Was this growth of the planets geologically slow or rapid? Did it take tens or hundreds of millions of years, or was it on the contrary largely accomplished in tens or hundreds of thousands of years? Was the material largely in dust-like or molecular form, or was it to a large extent in nuclei of considerable size? From these different postulates very divergent consequences may be traced in the formative stages of the earth; and finally the present nature of the earth itself may speak in favor of one or the other of these views.

Chamberlin, who has been the chief writer on this subject, adopts the hypothesis that the stages of earth-growth were very prolonged, even geologically speaking, and that the accretion was dominantly of dust-like or molecular particles. According to him the building up of the planets followed three stages: first, the direct condensation of the nuclear knots of the spirals into liquid or solid cores; second, the less direct collection of the outer, or orbital and satellitesimal matter; third, the still slower gathering up of the planetesimal material scattered over the zone between adjacent planets. This third factor, in Chamberlin's view, is regarded as very important and he believes this diffused matter contributed much of the earth substance, very slowly and in a dust-like form. This is one of the critical points in the details of the theory upon which turns much of the development of his following argument.

Chamberlin conceives the earth to have been built up as a solid body, not to have been fluid or viscous at any time later than the early nuclear stage and to have begun to hold an ocean by the time it contained 30 or 40 per cent of the present mass. Such liquid rock as was generated by compression or radioactivity during earth-growth is regarded as having been kneaded and squeezed to the surface, where it solidified approximately as fast as it was formed. In earth-growth, the denser planetesimal dust, he argues, tended to be somewhat segregated into the primitive ocean basins and served to maintain in them, as the earth was built outward, a greater density than in the elevated zones between, establishing thus a relation between density and elevation.

It seems a debatable question if such a large proportion of the added material was necessarily dust-like and capable of being weathered, sorted, and distributed by the primitive atmosphere and ocean. In fact, from this beginning of earth-growth the preponderance of the evidence appears to the writer to be against those sub-hypotheses which Chamberlin has followed. This evidence, its bearings and conclusions, will form the following parts of this article. It will be of ultimate value to both lines of argument that each may be weighed against the other.

HYPOTHESIS OF EARTH-GROWTH BY RAPID INFALL OF PLANETOIDS

Preliminary statement. Alternative views quite different from those which have been presented under the previous heading will now be discussed. It appears to the writer that the chemical character of the igneous rocks, the limited depth of density variations in the crust, the limited amount of salt in the sea, the rotation periods of the moon and planets,—all point to a molten condition of the earth at the completion of its growth. In the limited space available the more technical aspects of the arguments must, however, be omitted. The questions raised by this conclusion are: What mode of growth would have favored a molten state and how far did this precede the beginning of the geologic record, as given by the oldest rocks exposed at the surface of the globe?

Up to this point the method of alternative hypothesis has been pursued, and from the standpoint of scientific procedure it should be continued to the end. The limitations of space in a single essay, however, forbid. This subject, which for complete analysis should be developed in a volume, must be compressed into a few pages. The judicial style must often be abandoned for the declarative. Descriptions of some things which no eye has ever seen will be given graphically as though viewed by a witness. This change in method necessitated by limitations of space is, however, least objectionable in the closing parts of the subject, since the foundation hypotheses have been already presented and the argument leads from them toward the established facts of the geologic record.

Significance of the planetoids. The belt of asteroids, better called planetoids, appears to have remained more nearly in its original state than have other parts of the solar system. The lack of aggregation into a planet may be due in part to the absence of any dominating center. More than eight hundred of these bodies have now been discovered and listed and countless others must be so small that they will largely remain unknown. The diameters range from a maximum of 485 miles in increasing numbers down to 15 to 20 miles, the limit of telescopic visibility.

At some diameter below the limit of visibility in the telescope, although the number may be increasingly great, the summation of their masses must begin to fall off, since otherwise the combined bulk would produce a perceptible glow in the sky. Furthermore, Leverrier demonstrated from the limited perturbations of Mars in its orbit that the whole amount of matter distributed between the orbits of Mars and Jupiter cannot exceed about one-fourth of the mass of the earth. It may be less. In fact, later calculations limit it to less than one-hundredth of the mass of the earth. The rate of increase in numbers in the smaller visible sizes suggests in connection with the limitation in aggregate mass that a considerable part, perhaps a larger part of the matter, is not in dust-like or molecular form but is in fragments of appreciable size ranging up to some miles in diameter. These masses, owing to their small diameters and weak gravitative force, would possess almost no power to grow by accretion. They must retain almost the original state of the nebula, or better, the meteoritic swarm, and are perhaps as likely to have suffered occasional shattering and scattering by impact as to have grown from a lower order of size. Their evidence favors the hypothesis that the scattered matter which was added to the nucleus to form the earth was largely of such size that the individual planetoids would have plowed through a primordial atmosphere and ocean, if such existed, and have penetrated beneath the surface of the liquid or solid body below. The energy of impact from dust-like material would be absorbed at the surface and, as heat, quickly radiated into space. The accretion of dust would favor the growth of an earth solid throughout. Larger masses would, on the other hand, carry the energy of impact into the earth. They would not strike with the high velocities of the meteors which collide with the earth, since the different planetoids were traveling in the same general direction, but nevertheless a state of incandescence and liquidity would be likely to result from the sizes of the masses involved. If in addition the infall of masses was sufficiently rapid to bury the heat of previous infalls before it could be dissipated by conduction to the surface, a general heating and liquefaction of the earth would tend to take place, both from the increased compression of the deeper nucleus and the effects of impact at higher levels.[9]

The fact that the planets have cleared up the zones about them, whereas the planetoids have remained permanently in a scattered state, is an argument for holding that the existence of dominating nuclei determined the growth of the planets. It is likely that the nuclei were of various sizes, were clustered to various degrees, and many of them united by their impact. A somewhat limited number and considerable size of the units as well as their grouping would be in accord with the lack of relation of the amount of eccentricity and inclination of orbit to the masses of the several planets.

Indications of primordial tidal retardation. The moon keeps the same face turned always toward the earth. Consequently, from a point in outer space, it would be seen to rotate on its axis in exactly the same time that it completed its orbital revolution. Mercury is known also to keep the same face turned always toward the sun and the same relation is probably true of Venus. The other planets revolve many time on their axes during the period of revolution, the earth, for example, 366 times. The exact correspondence in the moon, Venus, and Mercury between their times of axial rotation and orbital revolution points to some causal relation between the two periods. That relation is one of tidal forces.

The moon distorts slightly the earth's figure, but as the tidal forces due to the moon are weak and the earth is very rigid, this distortion in figure is expressed mostly by the rise and fall of earth's fluid envelope. In so far as the body of the earth yields, it is an elastic yielding which involves no measurable expenditure of energy. The oceanic tidal waves tend continually to face the moon, and the earth revolves beneath them, like a wheel revolving between two opposite brake-shoes. This generates tidal friction which tends to slow down the axial rotation of the earth. There is no question as to the correctness of this theory, but there is a very serious question whether the forces are not so weak as to be without any geologic consequences, at least under the present rigid condition of the earth's interior.

---

[9] See note E, page 45.

Some of the latest work has been given to measuring directly the retardative influence of the tides, if such exists. MacMillan has made an estimate of the loss of energy by friction of the oceanic tides. He used the formulæ employed by engineers for the loss of head due to friction and viscosity, and applied them to the ocean. His conclusion is that the day would be lengthened by one second in about 500,000 years. Even if this figure be in error tenfold or a hundred-fold it is still in great contrast with the conclusion of Adams in the middle of the last century, that the earth was losing time at the rate of 22 seconds per century, a figure raised to 23.4 seconds by Darwin and lowered to 8.3 seconds by Newcomb. MacMillan's method brought to bear as a retardative agency practically all the friction of the tides, irrespective of their positions or directions of motions, and seems to show that the water tides do not have and have never had an appreciable effect on the earth's rotation.[10]

Tidal retardation if it has ever been an important factor in planetary history must then be chiefly due to a body tide. In so far as there is a mere elastic yielding of the body no energy is consumed, but a viscous drag will produce retardation. Recent measurements of the rigidity of the earth under tidal stresses, both by the horizontal pendulum and by the water level in a horizontal pipe, show that the earth as a whole is more rigid than steel and that under the exceedingly small tidal stresses the yielding is essentially elastic. The estimates of viscosity are so small that they are within the limits of error of the measurements. The smallness of the tidal strains in the earth may be appreciated by citing Darwin's calculations. According to this investigator, the tides raised by the moon upon the earth generate a stress-difference of 16 grams per square centimeter at the poles, 48 grams at the equator, and 128 grams at the center of the earth. Thus the earth is stressed by the lunar tidal forces even at the center to only about one part in fifteen thousand of the strength which granite has at the surface of the earth.

---

[10] MacMillan, W. D., "On the Loss of Energy by Friction of the Tides." In "The Tidal and Other Problems." Carnegie Institution of Washington, Pub. No. 107, 1909, pp. 71-75.

The tidal force exerted by the earth on the moon is about twenty-two times as great as the lunar tidal force on the earth, and reaches about one part in six hundred or seven hundred of the strength of granite. If the moon were once nearer the earth, the tidal stress-difference was much greater, varying inversely with the cube of the distance. Tidal retardation must have acted efficiently upon the moon, nevertheless, until the moon was at its present distance and the stresses reduced to their present magnitude, in order to have reduced its period of rotation to the same value as its final orbital period about the earth. The action must have been that of a viscous body tide since the moon has never been able to hold to itself an ocean envelope. The tidal force exerted by the earth upon the body of the moon consequently must have produced a notable viscous yielding and continued to do this in spite of increasing distance of the moon and increasing rigidity.

The far greater mass of the earth prevented such large effects of tidal retardation from being felt, but its period of revolution compared to those of Mars and the outer planets suggests that the tidal forces of the moon and sun have produced a notable slowing down of the earth also. The largest planet, Jupiter, 86,500 miles in diameter, revolves the most rapidly, completing one revolution in 9 hours 55 minutes; Saturn, the next largest, revolves in 10 hours 14 minutes. Uranus also shows by the pronounced polar flattening of its disc that it revolves in some similar short period. Mars, with a diameter approximately half of that of the earth and a twentieth of that of Jupiter, revolves in 24 hours 37 minutes. These planets can never have suffered largely from tidal retardation and a rough rule appears to prevail that the larger the planet the more rapidly it rotates. Judging from its mass, the earth may consequently have originally rotated in a period of between 15 and 20 hours. This argument is only of suggestive value, but it is in accord with other lines of argument. If the moon passed through a viscous state sufficiently prolonged for it to respond completely to tidal control in its rotation period, the presumption is clearly that the earth, a larger body and better able to retain its heat, also passed through a similar stage of viscosity. The present rigid and elastic condition of the earth appears then to be a secondary feature and the present ineffectiveness of the tides cannot be safely used as an argument against the strong indications of a primordial tidal retardation.

Significance of the oceanic salt. Sodium derived from the weathering of igneous rocks has been stored through all geological time in the ocean as sodium chloride. The ocean has grown more salty since it first gathered on the earth, yet it is so far undersaturated that sea water must be nine-tenths evaporated before sodium chloride begins to be precipitated. Furthermore, the indications are that it never was saturated, even though in primordial times the sea water may have been less in volume. Concentration to a degree which eliminates part of the sodium chloride raises the percentage content of bromine, magnesium chloride, and magnesium sulphate, so that sodium becomes subordinate to magnesium and the ratio of bromine to chlorine is increased Subsequent dilution would not change this ratio and the introduction of new salts could never bring it back to the original composition. The evidence from the sea itself is substantiated by the testimony of the sedimentary rocks. The amount stored as impregnations or as salt deposits in the sediments is quantitatively negligible, either as compared to the volume of the sediments or the mass of the oceanic salts. Salt deposits, furthermore, so far as known, began to be present only in the Paleozoic, in the later half of geologic time, the great masses of earlier sedimentary strata being barren of them.

It has been calculated that the total sodium in the ocean would be derived from the weathering and erosion over all the earth of a mantle of igneous rock of average composition only 2,300 feet thick, corresponding to 6,500 feet as the average thickness of erosion if restricted to the area of the continental platforms, including the lands and extending out to a depth of 600 feet below sea-level.

Daly has noted the significance of these facts upon the hypotheses of earth-growth.[11] Chamberlin supposes an ocean to have existed for long geologic ages upon the surface of the earth during its growth from a body about half of its present diameter and one-eighth of its present volume. The planetesimal material, he holds, was weathered and sorted into lighter and heavier portions, leading to the development of lighter protuberant and heavy depressed areas. The limited quantity of salt in the sea, however, is distinctly against such a hypothesis of oceanic antiquity and continental building. The amount of erosion in evidence where the older rocks are exposed as crystalline masses and from the great uplifted tracts of later times is apparently about sufficient to account for all the salt in the sea. In fact, the estimates of erosion through known geologic time based on the nature of rock exposures and the thickness of sediments have fully equaled or exceeded the amount given by the quantity of salt in solution. Weathering, erosion, and the accumulation of salt had therefore played no considerable part previous to the time recorded by the oldest rocks. The earlier physical conditions must have been very different from those which later prevailed.

---

[11] Daly, R. A., "Igneous Rocks and Their Origin," 1914, pp. 159, 163, 164.

Favored Hypothesis of an Earth Initially Molten

Indications of a primordial molten state. The indications of primordial tidal retardation and the limited amount of salts in the sea both point to the conclusion that the earth was molten at the completion of its growth. A molten state suggests a rapid earth-growth due to an original clustering of the matter whose convergence built up the planet. Larger nuclei hundreds of miles in diameter and smaller ones comparable to the planetoids moved in elliptic and nearly intersecting orbits. Mutual perturbations kept modifying these orbits and providing new chances for collisions, union, and growth. Such collisions led to a development of energy of impact sufficient to produce in the growing earth a molten state, at least in the outer portions. The earth kept growing at the same time by sweeping up large quantities of finer material, but a molten state suggests that the greater growth was due to the infall of larger nuclei. Finally, but one outstanding nucleus, the moon, was left beside the earth, and the earth-moon system attained a condition of stability and completed growth.

If the composition of the earth as a whole is similar to that of the meteorites, those samples of matter which come to us from the heavens, the most abundant material in the deep body of the earth is metallic iron. Now the blast furnace makes familiar the fact that slag is insoluble in iron and, being lighter, gathers in the upper part of the crucible, like cream upon milk. The slag is similar in composition to basaltic igneous rocks. The density of the deep interior suggests that it is layered like the crucible of the blast furnace and that the silicate rocks form an envelope some hundreds of miles thick, grading down into a great metallic core. The silicate envelope ultimately differentiated further, resulting in a rise of the more siliceous and lighter fraction into an outer layer, perhaps 50 to 75 miles in thickness. This in turn crystallized into a primordial, universal, granitic crust above a thicker basaltic shell below.

The primordial atmosphere. Granting the conclusions in regard to the initial fluid state of the earth, let the primordial atmospheric conditions be pictured. A gaseous envelope existing in equilibrium with rock magma would be dominantly water-vapor, followed in order of importance by carbon dioxide and carbon monoxide, chlorine and hydrochloric acid, with some nitrogen, but no free oxygen.

The present atmosphere of nitrogen and oxygen penetrates by solution into the liquid envelope of water. The primitive atmosphere of water-gas penetrated in the same manner by solution into the ocean of molten rock. But such an admixture of molten rock and water-gas is known to have a remarkable effect upon the melting point of silicate magmas. Under dry fusion the exalted temperature of 1300° to 1500° C., a dazzling white heat, is necessary to make granite thinly molten. But if the fluid rock has dissolved an abundance of water-vapor the mixture stays fluid until it has cooled below a temperature of 800° C. The surface of the earth when molten was perhaps no hotter than this. At such a comparatively low temperature and even at somewhat higher temperatures there would be but little dissociation of water into its component gases, and the earth would be capable of holding to itself, even in its molten stage, an envelope of water in the form of a deep and heavy atmosphere of water-gas. Such an envelope, including also an abundance of carbon dioxide and carbon monoxide, formed an effective thermal blanket, preventing a precipitous chilling and freezing at the surface of the ocean of molten rock.

The effectiveness of the blanket depended upon the peculiarity of both water-gas and carbon dioxide in being opaque to the slow vibrations of dark heat, absorbing these near the bottom of the primitive atmosphere and reradiating them from higher levels as long, slow heat waves. Strong convection currents carried up these heated gases from the superheated base to the higher levels of the atmosphere. There the chilling condensed the water-vapor into a thick and universal canopy of cloud, boiling up like thunder-heads from below, shedding continuously a downpour of acid rain, rain dissipated again into vapor as fast as the drops fell into the deeper and hotter strata of the atmosphere. The intensity of the vertical convection maintained a high electric tension. Incessant flashes of lightning linked as with living, fiery tentacles the cloudy heavens to the lurid molten earth. Tremendous reverberations of thunder, unsensed by mortal ears, shook the atmosphere in the worldwide primeval storm.

The sunlight of the Primordial Era illumined and was reflected from the outer side of the mantle of cloud. The planet shone brilliantly by this reflected light, having an external appearance similar to that which Jupiter and Saturn still possess. Above the zone of cloud the carbon dioxide and other gases, with very minor amounts of water-vapor, extended with diminishing density as an upper transparent envelope.

During the more rapid growth-stages the molecular and dust-like matter swept up by the earth settled like a never ceasing cloud of volcanic ash. The planetesimals of sand and gravel size were swept up by the earth many millions of times more abundantly than are meteors at the present time. Those meeting the earth with the higher velocities were consumed by impact. Over the hemisphere of night the otherwise invisible atmosphere above the cloud canopy scintillated with incessant flashes of light and trails of luminous dust. Bodies of larger size gave in their dissolution a still more brilliant display and penetrated to greater depths. At longer intervals, with titanic rush and roar, a greater projectile, tens or even hundreds of miles in diameter, cleaved through the canopy of cloud, leaving a tumultuous maelstrom behind, drove almost unchecked through the deep and dense atmosphere below, and, with worldwide commotion, was engulfed, with development of fervid heat, within the molten sea.

THE PASSAGE OF THE MOLTEN INTO THE RIGID EARTH

Density stratification by fractional crystallization. The central parts of the earth were compressed during the growth stages by the increasing load above. This compression developed heat, but also raised the fusion point and made for a greater rigidity. It is not known, consequently, whether during earth-growth the center tended toward a liquid or solid state. The outer part, however, with a thickness of perhaps the outer quarter of the radius, comprising about one-half of the volume of the sphere, seems to have passed into a truly molten condition.

The heavy atmosphere and canopy of cloud prevented a rapid radiation from the molten surface, probably sufficient during the highly liquid stage to prevent a crusting over of frozen rock. The method of solidification approached nearer to that which occurs in a large reservoir of magma intruded into the crust than to the freezing of a modern lava stream in contact with the air.

At last the rapid generation of heat by impact lessened, and the fluid sphere, seething with slow convection currents, began to cool. Certain compounds in the mutual solution of rock elements became insoluble and fractional crystallization was initiated. The heavy basic crystals were the first to form: crystals of metallic sulphides, magnetite, hornblende or pyroxene, and olivine. These crystals, because of their high specific gravity, tended to work downward in the convective movement. At first they were dissolved again in the abyss, but as time went on they remained undissolved and accumulated in the deeper parts of the fluid zone. The remaining magma was more siliceous, of lighter gravity, and in crystallization gave to the upper shell a higher proportion of feldspar and quartz. The original crust of the earth was consequently a granite. The process of fractional crystallization may, however, not be a sufficient explanation. An immiscibility of the complex mineral solutions may have developed upon the lowering of the temperature. In one way or the other or by a combination of several causes a density stratification is suggested by a number of lines of evidence as existing in the earth. The conclusion, then, is more than a mere inference from theories of crystallization.

The gathering of the ocean waters. At last the ocean of molten rock had shallowed, crystallization went forward in separate basins, convection became hindered, the surface froze as in a lava caldron. Then rain, ever descending from the shield of perpetual cloud, but never heretofore reaching the bottom of the atmosphere, at last began to splash on the hot surface of the earth. The raindrops at first were dissipated by contact and sent flying back as scattered molecules of gas. But, owing to the low conductivity of rocks, the transition stage was very brief, and perhaps even in a few thousand years from the time when the crustal congelation of the earth had taken place a permanent ocean of acid water began to rest upon the surface. For a while the balance swung, as one section or another of the crust was broken through and lavas would pour out abundantly. Rapidly, however, from the geologic standpoint, as the surface cooled, the atmosphere of water-vapor condensed in a never ceasing deluge until an ocean, probably universal in its extent, had gathered to a mean depth of several thousand feet. The remaining atmosphere was comparatively rare and cold. Carbon dioxide became the dominant gas, and water-vapor subordinate. Solar heat began to play the principal part in warming the equatorial zone. A system of planetary winds developed in accordance with the new order of nature. The cloud canopy became thin and broken, resolving itself into climatic belts. Sunlight for the first time began to pierce the lower atmosphere and illumine from without the surface of the earth.

During the earlier time, when the water could exist only as gas in the atmosphere, the great pressure of this envelope had kept much, perhaps most, of the gases in the molten rocks. With the great fall in atmospheric pressure which accompanied the gathering of the ocean, magmas which broke through the higher levels of the crust into the regions of this decreased pressure were able to give off great volumes of gases which in the earlier stage had been repressed. These gases, freed for the first time, are termed juvenile and from this time forward juvenile waters were added to the ocean. In the first ages following the solidification of the earth the additions were large in volume, but igneous action continues to bring new magmas to the surface recurrently from age to age. These give off the gases which have been repressed in them since the origin of the earth. Thus, in intermittent and lessened rate, the surface waters have increased through geologic time. As Suess has said, the body of the earth has given forth its oceans.

The Origin of Ocean Basins

The relations of crustal density to ocean basins. The fluid earth had a surface as level as the ocean, and the process of solidification which has been outlined does not account for those marked variations in density and in surface form which are expressed by the outer crust of the solid earth being divided into continents standing high above the ocean floors. A sketch of the formative period is therefore not complete unless the processes are briefly discussed which are thought to have shaped the earth's surface, giving rise to the existence of lands even before the period of the oldest known rocks.

Reasons will be given below for holding that the ocean basins have been formed by subsidence of broad areas of the crust, owing to the weight of magmas of high specific gravity rising widely and in enormous volume from a deep core of greater density into these portions of an originally lighter crust. This regional subsidence was especially characteristic of primordial times, but the process did not wholly cease then; since certain lines of evidence suggest that some ocean basins have been extended in later geologic ages, breaking into once wider continental platforms. The resultant increase in the volume of the ocean basins has led to a drawing off of the ocean waters from the continental areas, and a marked diminution of the shallow seas of earlier ages.

The cause of the continued generation of new bodies of molten rock in the sub-crustal shell, adequate to account for the observed results of later geologic time, is thought to lie in the slow accumulation of heat from radioactivity in these depths below the crust. This is discussed in the subsequent topic on the rise of basic magmas.

Some very thick bodies of intrusive rock are observed to be more dense and basic below, lighter and more siliceous above. The lower part is a gabbro, whereas the upper may be a granite. The separation has taken place after the intrusion of the magma, the denser material sinking, the lighter rising. There are indications that the process goes forward on a larger scale also, a scale so large that the dark and heavy base is never seen, erosion of later ages being restricted entirely to the granite zone. Such a splitting in composition is indicated in that the earlier intrusions in a period of igneous activity are intermediate or basic and the later products are vast bodies of granite. The greater density in the earth's interior suggests a primal density stratification on even a larger scale, which has been discussed under a previous topic.

But in the outer shell, 50 to 75 miles thick, the density is far from being uniform. In recent years it has been proved by means of precise geodetic measurements on the local intensity of gravity and deflections of the vertical that the crust beneath the continents is notably less dense than that beneath the oceans. The most of this difference in density exists probably within the outer 50 miles. The continents stand high, consequently, for the same reason that an iceberg rises above the surface of the sea: it is the position of equilibrium. At a certain depth the downward pressures given by the thicker continental and the thinner oceanic crust are the same and a condition of hydrostatic equilibrium prevails in the sub-crustal shell.

This condition of equal pressures at a certain depth is called isostasy. It is not inconsistent with a solid and rigid condition of the earth, but does mean that at a greater depth, apparently from 50 to 300 miles or more, hot but solid rock can slowly yield and flow by recrystallization. The process is physically the same as that by which a glacier flows under the slight stimulus of an almost level surface slope. The condition for such ready recrystallization is found in temperatures which are close to those of fusion. At such temperatures molecules under strain pass readily from the solid to the liquid

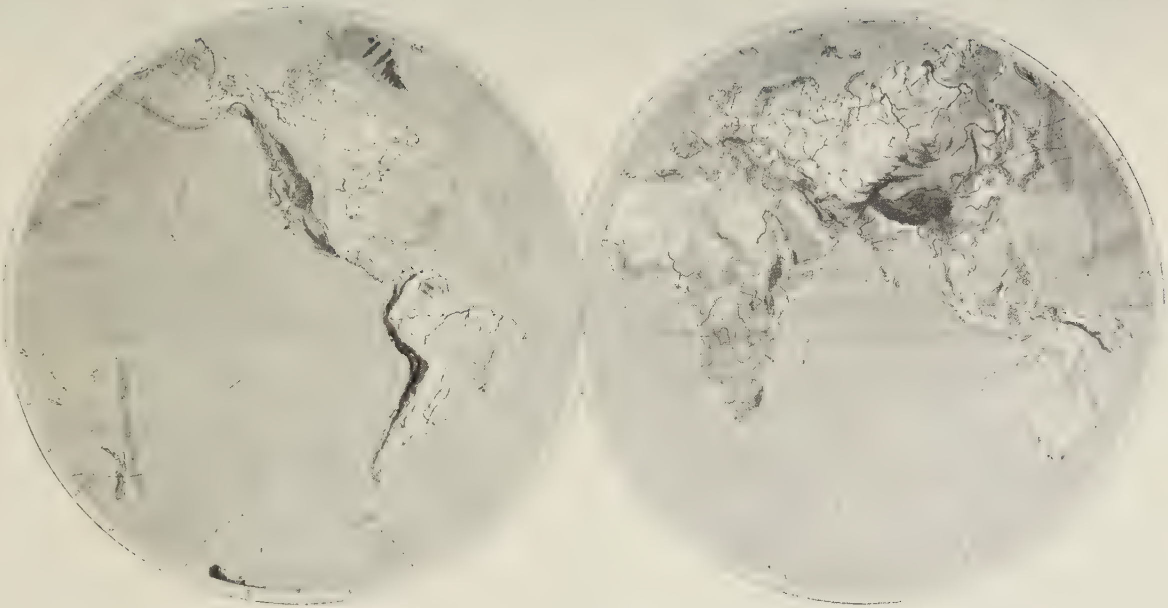


PLATE II.—The western and eastern hemispheres.

state, shift into positions which ease the strain, and again enter into a crystalline solid condition. The proof that such a process exists in the earth is based on several lines of evidence.

First, evidence of a broad isostatic equilibrium notwithstanding the agencies of mountain folding, of erosion, and of sedimentation, all of which work through geologic time tending to destroy those relations of elevation which are needed to maintain isostasy, giving equal pressures by broad crustal areas of unlike density upon the yielding zone below.

Second, the evidence of increasing temperature with depth, giving temperatures close to those of fusion at depths below 40 to 50 miles.

Third, the evidence from tides and earthquakes that the earth as a whole is more rigid than steel and cannot possess a fluid shell beneath the crust.

Fourth, the physical principle that at temperatures close to fusion a crystalline substance is incapable of supporting permanent shearing stresses, but yields slowly by recrystallization, notwithstanding the fact that under short stresses the same substance may be as rigid as steel.

The conclusion to which this argument leads is that an outer crust or *lithosphere,* the rock sphere, 50 to 75 miles thick and very strong, is marked by broad variations in density amounting to as much as 5 per cent, and more local variations up to 10 per cent, which correspond to the broader relief of the earth's surface. Below this lies a thick, hot, basic, rigid yet weak shell which the writer has named the *asthenosphere,*[12] the sphere of weakness. The problem of the origin of the ocean basins and of continental platforms resolves itself consequently into the origin of the density differences in the lithosphere and the maintenance of the heated and weak condition in the asthenosphere.

---

[12] Barrell, Joseph, "The Strength of the Earth's Crust." *Jour. Geology,* vols. 22, 23, 1914, 1915.

Rise of basic magmas from the asthenosphere. The series of radioactive elements slowly break down into elements of lower atomic weight and give off in the process enormous quantities of energy. Uranium, in degenerating through radium to the stable element lead, develops more than a million times the heat given by the combustion of an equal weight of coal, but the disintegration of the element and the liberation of its heat are so slow that the whole duration of geologic time has not sufficed to eliminate uranium from the crust of the earth. Therefore it has acted as a permanent generator of heat in the rocks which contain it.

Uranium and thorium, the parents of the radioactive series, are widely though sparsely diffused through the lithosphere. It has been calculated that, if they extend in their surface amount to a depth of 40 miles,[13] they must supply heat to the surface as fast as it is lost by radiation into space. The earth therefore appears not to be growing colder, though losing heat.

The small content of radioactive elements in the basaltic shell below the granitic crust of the continents would then supply that slow increment of heat which is necessary to generate new molten rocks. The granitic shell above, though somewhat richer in radioactive elements, is sufficiently near the surface to lose its excess heat by conduction. The excess heat generated in the asthenosphere is, on the contrary, so deeply buried that it cannot escape in that manner but must slowly transform some of the solid rock into liquid form. Reservoirs gather, until their mass, combined with their decreased density in the fluid form, enables them to work their way through the crust above and demonstrate their existence in igneous activity at the surface of the earth. The magma which thus comes from the greatest depth and in greatest volume would, because of the initial density stratification, produce a notable increase in the density of the outer crust.

---

[13] See note F, page 45.

In order to reëstablish isostatic equilibrium such a region must subside.

Most of the igneous rock of later geologic ages which has been intruded into the outer continental crust clearly has not increased the density sufficiently to produce a foundering and would appear therefore either to have come from somewhat higher levels or to have risen in lesser quantity. In some regions, however, as in that of the Lake Superior basin, large masses of basic magma do seem to have overweighted the crust in an early geologic period and produced a tendency to settle as a basin. The same effect may have taken place to even a larger degree in some regions of notable subsidence, as in the Mediterranean basins. In the earliest times, following the solidification of the earth, the forms and relations of the ocean basins suggest that dense molten matter from the depths of the earth broke into or through the outer crust, on a gigantic scale, eruption following eruption until the widespread floods had weighted down broad areas and caused their subsidence into ocean basins.

As seen in the lava plains of the moon, such an action, once started at a certain point, is conceived to have gone forward with widening radius, leading to the origin of the many rudely circular outlines characteristic of the ocean basins. The process left great angular segments of the original lighter crust as continental platforms standing in relief between the coalescent basins. The waters gathered into the basins and the continents emerged.

The Reign of Surface Processes and Beginning of the Archean

It is possible that shallow ocean basins began to form nearly as fast as the waters gathered, tending to maintain some land areas above the level of the primordial sea. Or the lands may have emerged later, as the ocean basins spread and deepened. With the separation of the lands from the seas, erosion began, carbon dioxide was abstracted from the atmosphere to make carbonates, and a further cause of atmospheric depletion was initiated. Thinner, rarer, and colder grew the gaseous envelope, until an oscillating balance was established between the supplies of new gases from the uprising molten rocks and the losses involved in the weathering of their solid forms. Nitrogen was at first relatively small in quantity and oxygen not present in more than a trace. An evolution in atmospheric composition had still to go forward through following ages to transform it into a gaseous medium for the support of the higher life. But even in the early periods following the gathering of the oceans and the emergence of the lands, the sun warmed the atmosphere and earth. An environment suitable for the lowest organisms had arisen and the earliest forms of life may not have been long in coming into existence. The reign of the surface processes had begun, but at age-long intervals, the still youthful energies of the interio broke forth. Magmas in great volume ascended, now seen a the most ancient granite-gneisses. In the great crustal overturning of these earliest revolutions the foundation rocks appear to have been everywhere destroyed. The oldest rocks preserved are mashed and crystallized sediments and lava sheet resting as fragments of a cover on the reservoirs of younge magma. Such sediments, altered and intruded, are th oldest Archean rocks. It is not known how close they stand in point of time to the formative processes whose description has been attempted. With these oldest rocks, the diml known, heroic and mythical eon of the earth is closed and th first historic eon opens as the remote and long enduring Archean division of geologic time.

NOTES

A. At the request of Mrs. Barrell and the Editor this chapter was read and revised in April, 1929, by Chester Ray Longwell, Professor of Geology, Yale University, to whom grateful acknowledgment is made. Certain changes have been made in the body of the chapter and other comments are given in the notes below.

B. Barrell's summary is not an entirely fair statement of the planetesimal hypothesis in its present form. The spiral nebulæ inspired some of the important ideas in the hypothesis; but after astronomers learned the vast scale of these nebulæ and something of their true character, Chamberlin and Moulton recognized that our solar system cannot be related directly to these objects. In expounding the hypothesis, however, the authors have continued to cite the spiral nebula as an illustration of the form to be expected in a small nebulous mass resulting from tidal disruption of a star. (See *The Two Solar Families* by T. C. Chamberlin, Chicago, 1928.) C. R. L.

C. Chamberlin considered the possibility that the moon was not in the earth's sphere of control at first, but was captured at a later stage (*The Two Solar Families*, pp. 188-190). C. R. L.

D. This paragraph has lost its force, as a criticism of the planetesimal hypothesis. As Chamberlin states in his last work (*The Two Solar Families*, p. 144), "The spiral form is thus more a matter of interest than of importance." C. R. L.

E. Since Barrell prepared this article, Jeans and Jeffreys have proposed another important modification of the Chamberlin-Moulton hypothesis. This modification assumes less dispersion of material from the primary bolts or knots, and a liquid stage of the earth resulting directly from condensation of the original gas (See *The Earth*, by H. Jeffreys, Cambridge, 1924). C. R. L.

F. This estimated depth to which the radioactive elements extend in considerable quantities has been greatly reduced by Jeffreys and others. C. R. L.

THE GEOLOGICAL TIME TABLE

(*To accompany Chapter II*)

Present time.

Psychozoic era. Age of Man or Age of Reason.

Includes the present or "Recent time," and the time during which man attained his highest civilization. De Geer calculates on the basis of ice retreat in Sweden that this time began 8,500 years ago.

Geologic time.

Cenozoic or Modern era. Age of mammal and flowering-plant dominance.

Glacial or Pleistocene epoch. Last great ice age and rise of communal man.

Pliocene epoch. Rising of lands and cooling of climates. Development of man from ape-like forms.

Miocene and Oligocene epochs. Rise of apes.

Eocene epoch. Rise of cereals and fruits and of higher mammals and monkeys.

Mesozoic or Medieval era. Age of reptile dominance.

Cretaceous period. Rise of primitive mammals, flowering plants, and higher insects.

Jurassic period. Climax of conifer and cycad forests. Rise of birds and flying reptiles.

Triassic period. Rise of cycads, dinosaurs, and reptilian mammals.

Paleozoic or Ancient era. Age of primitive plants and animals.

Permian period. Rise of reptiles and conifer forests. Another grea ice age in middle Permian time.

Carboniferous time or Age of Amphibia. Rise of insects and sharks Time of greatest coal accumulation.

Devonian period or Age of Fishes. First forests, spiders, and amphibians

Silurian period. First known land floras.

Ordovician period. First fresh-water fishes.

Cambrian period. First shell-bearing marine animals, and dominanc of trilobites.

Proterozoic era. Age of small shell-less marine animals. An early and a lat ice age.

Archeozoic era. Origin of protoplasm and of simplest forms of life.

Cosmic time.

Formative era. Birth and growth of the earth out of the spiral-lik nebula of the sun. Beginnings of the atmosphere and hydrosphere, an of continental platforms and oceanic basins. No known geologica record.

CHAPTER II

THE EARTH'S CHANGING SURFACE AND CLIMATE DURING GEOLOGIC TIME

CHARLES SCHUCHERT

PROFESSOR OF PALEONTOLOGY, YALE UNIVERSITY, EMERITUS

UNIFORMITY OF NATURE. In the previous chapter the probable origin of the earth was sought in far-off space among the stars by examining them through the great telescopes of our time, through the light-sensing chemical plate of the photographic camera, and through the even more wonderful spectroscope. With this knowledge in hand, postulate upon postulate has been tried out through that talismanic study, mathematics, and so through astronomy and the science of numbers there is revealed an earth evolution still hazy, to be further established through geodesy, mechanics, and chemistry before the geologist comes to be its interpreter. Then, hand in hand with the geologist, the paleontologist, or student of ancient life, reveals the organic hordes that have gone on and through whose fossil remains is unraveled the history of the earth. In all of this we see the brotherhood of the sciences and the fundamental postulate of the uniformity of nature.

Origin of the sun and earth. Professor Barrell, in the previous chapter, pointed out that the sun is a star, and one of the smaller among the countless millions seen through the telescope. It may have had its origin in a diffuse nebula like Orion, and, according to the disruption hypothesis of Chamberlin and Moulton, had a long antecedent history before it gave birth to its planetary system. Therefore before there was an earth, the sun had been condensing and moving undisturbed in space for countless ages, until it came within the influence of another and a greater star. The gravitative influence of this mighty passing intruder acted catastrophically upon the sun and caused its partial disruption. As a consequence, from opposite sides of the sun there streamed rapidly outward materials of its own mass that soon arranged themselves into a two-armed luminous nebula with a spiral form. The mass which was so extruded, and which did not fall back again into the sun, was less than 1 per cent of the sun's mass, and yet it gave rise to the planetary system which encircles the parent body. From this we also the more readily appreciate the great size of the parent sun, whose volume is 1,300,000 times greater than that of the earth.

Growing earth during the Formative era. In the solar nebula of bi-parental origin there existed eight knots of more or less loosely aggregated denser and hotter matter, the nuclei of the future minor and major planets and their satellites, and these in the course of time attracted to themselves most of the surrounding nebulous material, usually spoken of as the planetesimals. The earth-knot, it is estimated, may have had an original diameter of about 5,500 miles, and the moon-knot perhaps half its present diameter of 2,162 miles. In the course of cosmic time, the earth and moon, revolving as companions about the sun, gathered into themselves the planetesimals that lay within their spheres of influence.

The writer holds to the postulate of Barrell that the planetesimals conceived by Chamberlin to have been of the size of sand and dust were probably for the most part much larger and more like the planetoids in dimensions. From time to time, as one or more of the planetoid-like bodies, singly or in combination, plunged in upon the earth with velocities up to tens of miles per second, their impact with and engulfment by the earth engendered much additional heat. In fact, they liquefied themselves and their earth surroundings as a result of their great impacts. Furthermore, the high internal heat of the earth was accentuated by the condensation accompanying the increase of mass from an original earth diameter of 5,500 miles to one initially larger than 8,100 miles. At no time, however, does it appear that the earth was necessarily in an astral condition, shining like a star.

The present diameter of the earth is 7,918 miles, but at the close of the growing period it must have been 200 and possibly even 400 miles greater, for it is believed by geologists that throughout geologic time it has been losing volume, due in part to the loss of heat into space, but probably in greater degree to internal molecular rearrangements. It may well be that the crust of the earth does not adjust itself continuously and uniformly to the shrinking core, but yields only along local zones of weakness, at widely separated time intervals, giving rise to the complicated folding of rocks in mountain belts. Even though the earth has been dissipating its inherited and derived energy for at least one thousand millions of years, and in so doing repeatedly giving birth to new series of mountains, our mundane sphere is still far from having attained the internal stability that will, when achieved, result in a featureless earth, an atmosphere devoid of the carbon dioxide that is the basis of life, and a universal lifeless ocean — the facial expression which the earth, it is thought, will have in its old age.

Volcanism during the Formative era. While the earth was internally very hot and viscous, the body-mass was in slow movement, with the heat ever rising toward the surface. These movements simulated a slow boiling process, and the upwellings of the molten matter repeatedly broke through the outer cold shell and engulfed it. As the cold crustal masses descended, they liquefied, and in expanding brought about increased pressures that again found relief in the rising tongues of heated matter. This condition is believed to have continued for a very long time, and to have been particularly active during the last half of the Formative era and the first era of geologic time, an age that may have endured for one-eighth to possibly one-fourth of the earth's entire history. The boiling process not only disseminated the internal heat, but also brought about an irregular sorting out of the heavier and lighter substances, so that the more basic and metalliferous materials as a rule sank to ever lower levels, while the less heavy acidic ones rose as granite rocks toward the surface of the earth, making the more elevated continental platforms. Finally, at the close of the first era of geologic time, the Archeozoic, the lithosphere or outer rocky and more or less rigid shell may have had a thickness of 30 miles. Through such a rocky mass little of the internal heat rises to the surface, and life would be impossible on the earth if it were not for the constant flow of the sun's radiant warmth, made equable and usable by the atmosphere. These conditions were already present in the Archeozoic era.

Origin of continents and oceanic basins. It is well known to geodesists and geologists that the continents are built of lighter materials, essentially of granites, while the greater oceanic areas have the heavier basaltic rocks beneath them, and that the difference in specific gravity amounts to about 3 per cent. We have seen that these differences came about seemingly as a result of the internal boiling process that prevailed during the Formative era and the Archeozoic, and so it appears that the higher continental masses and the depressed oceanic basins came into being very early in the history of the earth. A similar interrelation of masses is also to be seen in the moon.

This is the igneous theory of the origin of oceanic basins and continental platforms of Barrell, and it holds that the differentiation took place after the earth had attained its complete growth, in other words during the closing time of the Formative era and during the Archeozoic era. The differences between the densities of the lands and oceans are held by Barrell to be only skin deep—in the outer one-fiftieth of the earth's present radius, or in the outer shell of about 75 miles in thickness.

On the other hand, it is true that the lands throughout geologic time have repeatedly gone down as well as up, but the sum of their movements has been upward, and for this reason geologists speak of them as the positive areas of the earth's surface. In the same way, the lower-lying fields have also risen locally at times, but their movement has in the aggregate been downward, bringing about the increasingly greater oceanic basins, the negative areas, by far the largest of the earth's surface. We shall see later on that the oceanic fields have become larger at the expense of the lands to accommodate the ever increasing volume of water, and it therefore naturally follows that the continents in former geologic times were considerably larger than they are now, possibly even 25 per cent larger. But the newer geology no longer holds to the theory that the oceans and lands have repeatedly changed places; quite the contrary, we agree with Dana that the present positions of the land and water areas have been more or less permanent throughout geologic time.

Origin of the atmosphere. It was not so long ago that most geologists held with the French astronomer Laplace and with Dana that the earth was originally very hot, and that all of the water of the hydrosphere, the salts of the oceans, and the carbon dioxide of the air and oceans had been parts of the primal gaseous envelope. Not only this, but that the latter also included all the carbon locked up in the rocks, estimated to be 30,000 times greater than the amount now in the atmosphere. Accordingly, as the earth was held to have been cooling throughout its history, it was thought that only recently, geologically speaking, was the present thin condition of the atmosphere brought about.

Even though more than sixty years ago a few English geologists who were familiar with the geology of India and Africa began to point out that the earth had passed through a cold period toward the close of the Paleozoic era (see Figs. 4 and 5), this discovery did not at once break down the teachings of Laplace and Dana. When, however, still older glacial periods began to be discerned in the stratified rocks and especially in the oldest ones near the beginning of the Proterozoic era (see Figs. 7 and 8)—a record that is remarkably well preserved in Canada—the final straw was at hand to break down the theory that the climates of the earth had passed progressively from an astral through a torrid to a temperate condition, along with a slow clarifying of the atmosphere (see Figs. 3-8).

The newer geology holds, with Chamberlin, that the growing earth was originally too small in mass to hold an atmosphere and accordingly there was a time when our planet had none. As it grew in diameter, the earth was more and more able to hold an atmosphere and a hydrosphere, and during the long growing period there was finally originated an atmosphere probably not much unlike the present one, which in a roughly approximate way may be said to be composed of four-fifths nitrogen and one-fifth oxygen. It should, however, be noted here that at first the atmosphere had but little oxygen. Since life came to be, using the carbon and freeing most of the oxygen of the carbon dioxide of the atmosphere, the quantity of free oxygen has more or less steadily increased, though at all times much of it has been consumed in the oxidation processes of the rocks and minerals.

The most constant accessory constituent of air is carbon dioxide, one of the three fundamental materials at the basis of life. In the present atmosphere there are about three volumes of this gas to 10,000 of air, and there is as much more in living things as there is in the atmosphere. On the other hand, there is in the oceans of today, according to F. W. Clarke, the geochemist, from 18 to 27 times more carbon dioxide than in the air (Johnston and Williamson say that at 15° C. there is about 70 times more), while the still vaster volumes locked up in the sedimentary rocks and in the fuels and carbonaceous deposits of the earth are computed to be 30,000 times greater than the volume in the present atmosphere. These facts are brought forward at this time to show that the constituents of the atmosphere have always varied because of the constant loss of carbon dioxide and oxygen to the sedimentary rocks, but that at the same time there has always been a resupply of carbon dioxide through the ever active volcanoes and the mineral springs, and of free oxygen through the life activities of plants. Holmes says:[1] "Even now, the outer 70 miles of the earth's crust would be competent to supply all the nitrogen of the atmosphere, the water of the oceans and the vast quantity of carbon dioxide represented by limestones and carbonaceous deposits."

It has been well said that if volcanism should cease it would not be long before the existence of life would be impossible because of the absence of carbon. We should add here that if there were again as much life as there is at present, all the carbon of the atmosphere would be in the living plants and animals, and, if such a condition were possible, death would come to them all. Therefore life and its abundance at any time are conditioned by the amount of this gas present in the atmosphere.

Climates of the past. The quantity of carbon dioxide in the atmosphere is to a certain extent also a climatic regulator, though the greater factor in this matter is water-vapor, which is also the most variable constituent of the atmosphere. With

---

[1] Holmes, A., "The Age of the Earth," 1913, p. 30.

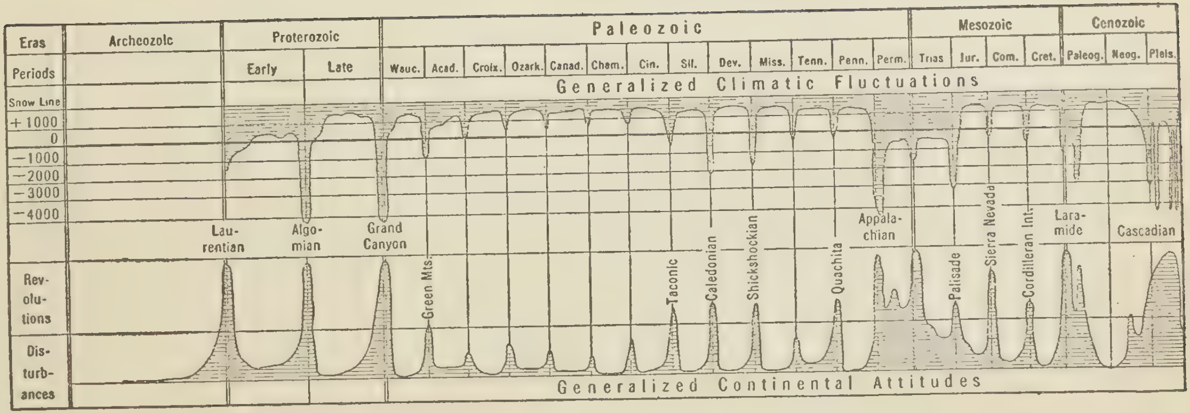


FIG. 3.—Diagram showing the times and probable extent of the more or less marked climatic changes in the geologic history of North America, and of its elevation into chains of mountains.

a greater abundance of both, and especially of aqueous vapor, there results a thickened atmospheric blanket that not only holds in more of the earth's warmth but takes up greater amounts of the sun's radiations, and when there is less of this gas and of water-vapor the climates are thinner and cooler. The amount of carbon dioxide and water-vapor in the atmosphere has varied much throughout the geologic ages.

Huxley in his interesting book *Physiography* has well said that without the sun "There could neither be rain nor rivers. . . . Rain is dependent for its distribution upon currents in the atmosphere, but these currents are due to disturbances of equilibrium which are brought about by means of solar heat. Without the sun, then, there could be no winds." The currents of the sea in their final analysis are also due to the heat of the sun. Therefore through the radiant action of the sun, water-vapor is added to the atmosphere, and the amount of it is at present and always has been the latter's most variable constituent, and, as rain, is of the greatest importance geologically. Clarke states[2] that water "is not merely a solvent and disintegrator of rocks, but it is also a carrier, distributing other substances and making them more active. To the circulation of atmospheric moisture we owe our rivers, and through them erosion is effected. The process of erosion is partly chemical and partly mechanical, and the two modes of action reënforce each other. By flowing streams the rocks are ground to sand, and so new surfaces are exposed to chemical attack. On the other hand, chemical solution weakens the rocks and renders them easier to remove mechanically. . . . It is through the agency of rain or snow that the atmosphere produces its greatest geological effects. . . . Aqueous vapor dissolves and concentrates the other ingredients of air, and brings them to the ground in rain."

---

[2] Clarke, F. W., "The Data of Geochemistry." U. S. Geol. Survey, Bull. 491, 1911, p. 48.

We are living at a time when the earth has marked climatic differences, varying between icy polar climates and hot moist or dry tropical conditions. This has, however, not always been the case, for not long ago geologically the temperature of the entire earth was even colder than it is now, although most of the climates of the past have been warm and fairly equable the world over (see Fig. 3). The ancient plants and animals are "self-registering thermometers" with regard to the climates of the past, and they indicate that warm climates persisted during long geological ages, and that even though there were at all times zonal belts and fluctuations in the temperature, the polar areas were usually inhabited, as is now well known, by plants and animals of kinds that were adjusted to winterless environments. These temperature fluctuations were greatest during the closing and opening stages of the periods and eras.

The very long warm times were separated by short periods of cool to cold climates. Geologists now know of seven periods of decided temperature changes (*earliest and latest Proterozoic,* Silurian, *Permian,* Triassic-Lias, Cretaceous-Eocene, and *Pleistocene*), and of these at least four (those in italics) were glacial climates). Cooled climates occur when the lands are largest and most emergent, during the closing stages of periods and eras, and cold climates nearly always exist during or immediately following the times when the earth is undergoing most marked mountain making (see Fig. 3).

Origin of the earth's waters. There was a time when the earth was too small in mass to hold a hydrosphere, the envelope of water that lies beneath the atmosphere and above the rocky surface of the planet. As the earth grew in mass, it became more and more possible for it to have standing bodies of water and clouds of water-vapor floating with the winds of the atmosphere. All of this water, the newer geology

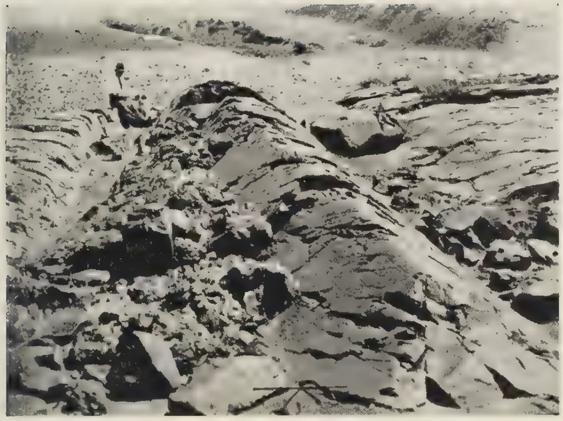


FIG. 4.—Glacially striated diabase, made in middle Permian time. Vaal River north of Kimberley, South Africa. Photograph by W. M. Davis.

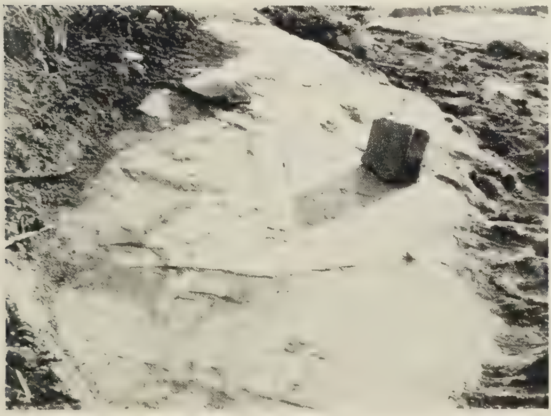


FIG. 5.—Lower Cambrian quartzite, striated in middle Permian time. Inman Valley, South Australia. Photograph by T. W. E. David.

thinks, came forth out of the earth itself, through volcanic activity and thermal springs. Even though some of the superficial waters vanish through soaking into the cold earth-shell, their volume has increased throughout geologic time; the greatest amount was added during the later part of the long growing period of the earth and during the Archeozoic era, when from 25 to 50 per cent of the present volume is believed to have come into existence. The rest has been added during subsequent geologic time.

Source of the salts of the oceans. It is well known that the seas and oceans are salty, and that on the average there are 3.5 pounds of saline matter to every 100 pounds of marine water, and in each 100 pounds of sea salts there are nearly 78 pounds of sodium chloride or our table salt. Clarke has estimated that if all of the saline matter of the oceans were concentrated, and the volume placed on the United States, its surface would be completely covered to a depth of 1.6 miles. As all of this saline matter has been leached out of the rocks of the dry lands since the earth has had rains, and as very little of it, comparatively, has been taken out of the ocean by the accumulating rocks, it has been further estimated that it represents the breaking down of a mass of average igneous rock equal to at least 6,500 feet in thickness over all the continental platforms. Probably it is more correct to state that the continents have suffered erosion of igneous rocks amounting to between 1 and 2 miles of average depth. Of course all erosion throughout geologic time was far greater, perhaps, as Barrell states, from 50 to even 100 per cent higher. It included the reworking of older materials, igneous and sedimentary. Furthermore, "more than a half, perhaps four-fifths, of the erosion of igneous rocks was accomplished before the beginning of the Paleozoic" (Barrell).

Various computations have been made as to how long it has taken the salts in the oceans to accumulate and the best of the older calculations arrive at about 100 million years. This figure is based on the postulate that the present rate of stream deliverance derived from a few rivers is about the same as the rate throughout geologic time. We now know that the calculated present rate of salt deliverance is not only erroneous, but in all probability very much so. In most rivers we do not know the volume of water annually discharged into the ocean and, furthermore, the rate was highly variable during geologic time as will be seen from the evidence presented throughout this chapter. Accordingly, the assumed present rate is believed to be entirely too high for the average of geologic time, and when all the factors are known, it will be seen that the salt in the sea and locked up in the rocks has taken as long to accumulate as the age indicated for the earth on the basis of the disintegration of radium-bearing minerals, namely, of the order of 1500 million years.

Origin of the sedimentary strata. The great variability of geologic climates also leads to variations in the power of the atmosphere to weather and break down the high places of the lands. The earliest atmosphere, far richer in carbon monoxide and carbon dioxide than subsequent climates, was a most active weathering agent in dissolving and breaking up the oldest rocks of the lithosphere, the igneous basaltic and granitic rocks. Then, too, there had not yet developed a vegetation on the most ancient lands to hold the fast-forming soils, and these conditions made it inevitable that all of this loose and solvent material should be rapidly washed by the rains and rivers into the oceanic basins. Therefore the stratified or water-laid rocks accumulated during the earlier geologic eras more quickly than in the later ones. On the other hand, the erosive power of both air and water has varied much throughout geologic time because of the periodically varying height of the land and the ever changing humidity and temperature of the air. Accordingly, the rivers carry small loads of sediments during long stretches of time and at other times

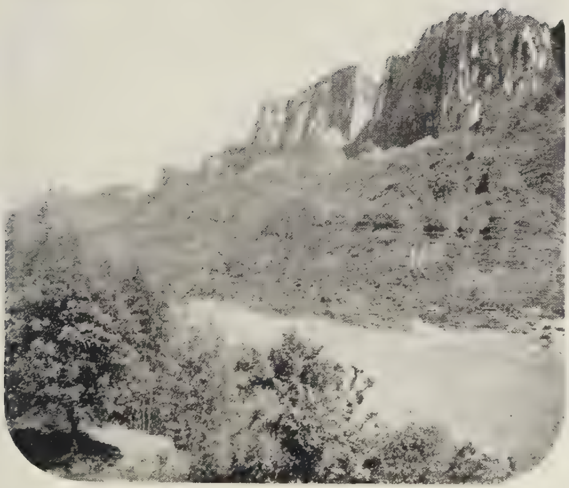


Fig. 6.—Glacial bowlder beds beneath thick formations of dolomite on the upper Yangtse River, China, in latitude 31° N. Age of till, late Proterozoic. Photograph by Bailey Willis. Published in "Researches in China," Publication No. 54, Vol. 1, 1907, of the Carnegie Institution.

their load is much greater. If the erosion on the land is rapid and the rivers are not long, the land débris is apt to be coarser n grain and less well assorted, but of whatever nature the waste of the lands is, the rivers finally deliver it to the seas and oceans; and here the materials are subjected to a long process of reworking and assorting into muds and sandstones. As all of this work is done in waters, as the character of the sediments varies, and as the wave-power is variable with the winds from day to day, it follows that the materials must be laid down in horizontal sheets of different kinds of rock that make up the strata of the stratified rocks. From this it is apparent why the sedimentary rocks of the earth's outer shell not only are of different kinds, but why they so often occur in more or less long cycles of deposits that begin with coarse sandstones or even conglomerates and pass upward into the much finer-grained mudstones and finally into limestones. The limestones are in the main the deposits due to the chemical activities of organisms or the accumulating débris of plants and animals. Geologists therefore speak of limestones and chalks as organic deposits. So throughout the geologic ages, cycle upon cycle of sedimentation succeeded one another, the débris of successive ranges of once majestic mountains, and in this orderly sequence of deposits lies buried much of the life of the past.

The United States Geological Survey stated in 1912 that the surface of the United States is being removed by solvent denudation at the average rate of .0013 of an inch a year, or 1 inch in 760 years. This means a removal by the streams of over 270 million tons of dissolved matter and 513 million tons of suspended matter annually. In other words, there is delivered into the seas and oceans each year from the area of the United States alone 783 million tons of rock materials. The amounts removed from different drainage basins show interesting comparisons. In respect to dissolved matter, the southern Pacific basin heads the list with 177 tons per square mile per year, the northern Atlantic basin being next with 130 tons. The rate for the Hudson Bay basin, where the topography is nearly flat and the rocks are mainly granites, is lowest, with 28 tons.

Holmes states[3] that the known denudation rates vary between 1 foot in 400 years (Irawadi basin) to 1 foot in 47,000 years (Hudson Bay region). For North America the rate for solvent denudation is 1 foot in 30,000 years, and for mechanical removal 1 foot in 12,000 years. "Taking both together, the average rate of denudation is found to be 1 foot in 8,600 years."

The ancient life is known to us in the countless fossils of the rocks, for they are the remains of plants and animals living on the lands and in the seas at the time when the sediments were accumulating. Most of them, like the shellfish, lived on or in the bottom of the seas, other active forms swam about in the water, while the remains of the plants and animals of the lands were drifted by the streams into the marine areas, where they eventually sank to the bottom and came to be covered over—buried—by the accumulating sands, muds, or limestones. It should, however, be added that but little of the life of any time is preserved as fossils, for much of it is too soft to be preservable, or it is eaten or destroyed by other organisms or reduced by the solvent powers of bacteria and the acids of the waters.

The record of the physical forces which automatically entomb the successive upwellings of life is found upon all the continents, but is woefully incomplete in any one. For many cycles the marine record is best in North America, at other times in Europe or the Mediterranean countries or in Asia. The land or fresh-water record is even more scattered and imperfect, with the longest history in Africa, a continent that, south of the Sahara desert, has been invaded but little

---

[3] Holmes, A., *op. cit.*, p. 57.

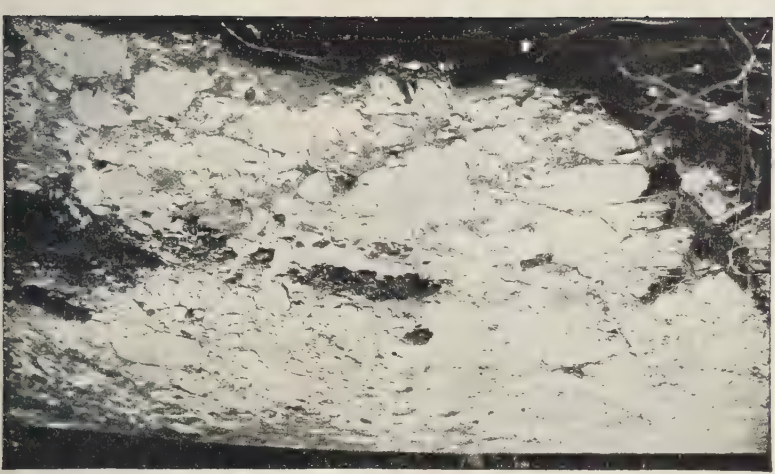


FIG. 7.—Eroded exposure of the oldest known glacial deposits (Lower Huronian bowlder bed), near Cobalt, Ontario. Photograph by A. P. Coleman.

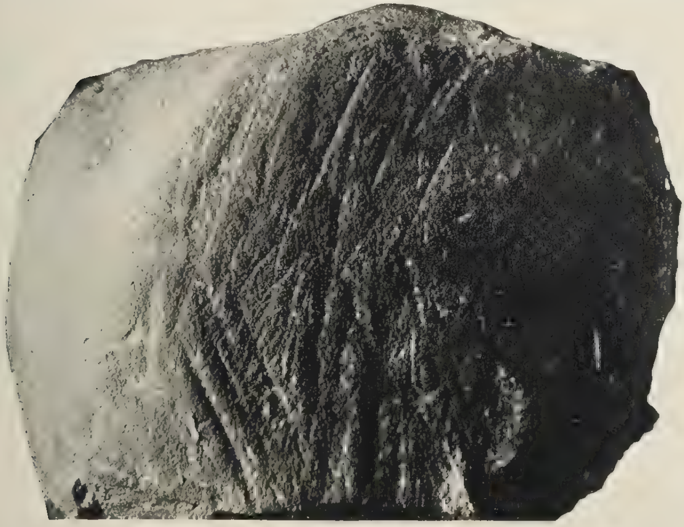


FIG. 8.—Striated bowlder taken from the oldest known glacial deposits. Photograph by A. P. Coleman.

by the ancient oceans. Out of all these widely scattered records the geologist pieces together the geological column, embodying the history of the earth, and yet at best we seem to have recovered far less than half of it. The record may be complete in the oceanic basins, but here it is forever hidden from hammer and mind. However, if we piece together into a superposed sequence all of the thicker geological formations of marine sandstones, mudstones, and limestones known in North America after the beginning of the Paleozoic era, we get a pile of about 265,000 feet in thickness (= 50 miles). When, however, the greatest thicknesses in North America are combined with those of Europe, the grand total rises to about 310,000 feet (= over 58 miles). Even so, the geological record is still very imperfect, and it therefore seems safe to say that geologists will eventually know of Paleozoic, Mesozoic, and Cenozoic marine strata a total thickness of not less than 400,000 feet (= about 75 miles). This means the more or less rapid wearing away almost to sea-level, one after another, of more than twenty ranges of mountains like the present European Alps or the American Rockies. During the incredibly long intermediate times, when the lands were planed to a low relief, there was very little erosion.

The above mentioned known and predicted depths of the geological column represent, however, only about one-third of geologic time, and there is every reason to believe that erosion and deposition were as great during the Proterozoic and Archeozoic eras. Accordingly the total depth of the geological column will eventually attain to the stupendous figure of 225 miles! At present, geology has revealed a thickness of about 90 miles.

Taking the predicted depth of the geological column in its thickest development, this means that one foot of sandstone has accumulated on the average in something like 750 years, one foot of shale in 1000 years, and one foot of limestone in 2350 years. These figures must not, however, be taken too literally, and all that they show is the quickest average deposition where the formations are thickest; in general, the sediments have taken longer, and probably much longer, to accumulate, since in most places the formations are decidedly thinner than the above given maxima.

Ratios of muds, sandstones, and limestones. We have seen that the continents have lost through atmospheric erosion a layer of igneous rock between 1 and 2 miles thick in the course of geologic time. This amount of eroded average igneous rock should theoretically resolve itself into 30 per cent of solution materials and 70 per cent of detritals, or 80 per cent of mudstones, 11 per cent of sandstones, and 9 per cent of limestones. Holmes gives 70 per cent of shales (20 per cent quartz), 16 per cent of sandstones (75 per cent quartz), and 14 per cent limestones (75 per cent calcium carbonate). However, actual observations of the stratified rocks of America and Europe show quite different percentages for these three categories of water-laid sediments, and the difference is due to a great increase of pore-space in the fragmented materials and to the addition of material extracted out of the atmosphere and hydrosphere during the weathering processes. Accordingly, Leith and Mead[4] have shown that the cubical content of average igneous rocks thus increases in volume by at least 28 per cent, and that on the continents we appear to have 48 per cent of mudstones, 32 per cent of sandstones, and 20 per cent of limestones. This marked difference beween chemical theory and actual presence is further explained by the unknown quantitative loss from the continents of the finest muds, sands, and solvent materials that the lands have permanently contributed to the oceanic basins. On the basis of the circulation of radium, Holmes estimates that the loss from the lands to the deep-sea deposits is about one-thirtieth of

[4] Leith, C. K., and Mead, W. J., "Metamorphic Geology," 1915, pp. 59-97.

all the material eroded, i.e., about 300 million tons of the 9,000 million tons annually.

Distribution of the sedimentary rocks. We have seen that, according to theory, all of the continents have lost a layer of original igneous rock that is on the average between 1 and 2 miles in thickness, and it is this material, removed and reworked time and again by the weathering processes and the further chemical and assorting agencies of the rivers and oceans, that has gone into building the known geological column, with its maximum summation thickness of 90 miles. In no one place, however, can be seen more than a small part of this record, for usually the local thickness is under 1 mile, though there are limited regions where as much as 20 miles of it is visible. This is because the deposition of the geologic formations in the periodically rising and flooding oceans, as described later in this chapter, takes place at any given time in very limited areas, most commonly, as at present, along the margins of the continents, or in long and narrow troughs — the geosynclines (see Fig. 9) — within the continental borders, and only periodically over the wider inner portions of the lands. We may add that over the surface of one-third of North America the visible rocks are all of igneous or crystalline character, that over more than one-half of it the thicknesses of the sedimentary rocks are under 1 mile, and that over the remaining small portion they vary from 1 to 20 miles; yet the greater depths do not cover more than one-eighth of the continent, and they occur in the long and narrow troughs of sedimentation, of which the two best known lie in the Appalachian and Rocky Mountain regions (see Fig. 9).

Eras of geological time. Now let us see how geologists divide this great pile of at least 90 miles of sediments and their included fossils. (A synopsis of geologic time is presented on page 46, and in Fig. 3.) The first era, or *Archeozoic* time, with the oldest known strata, has no proved fossils,

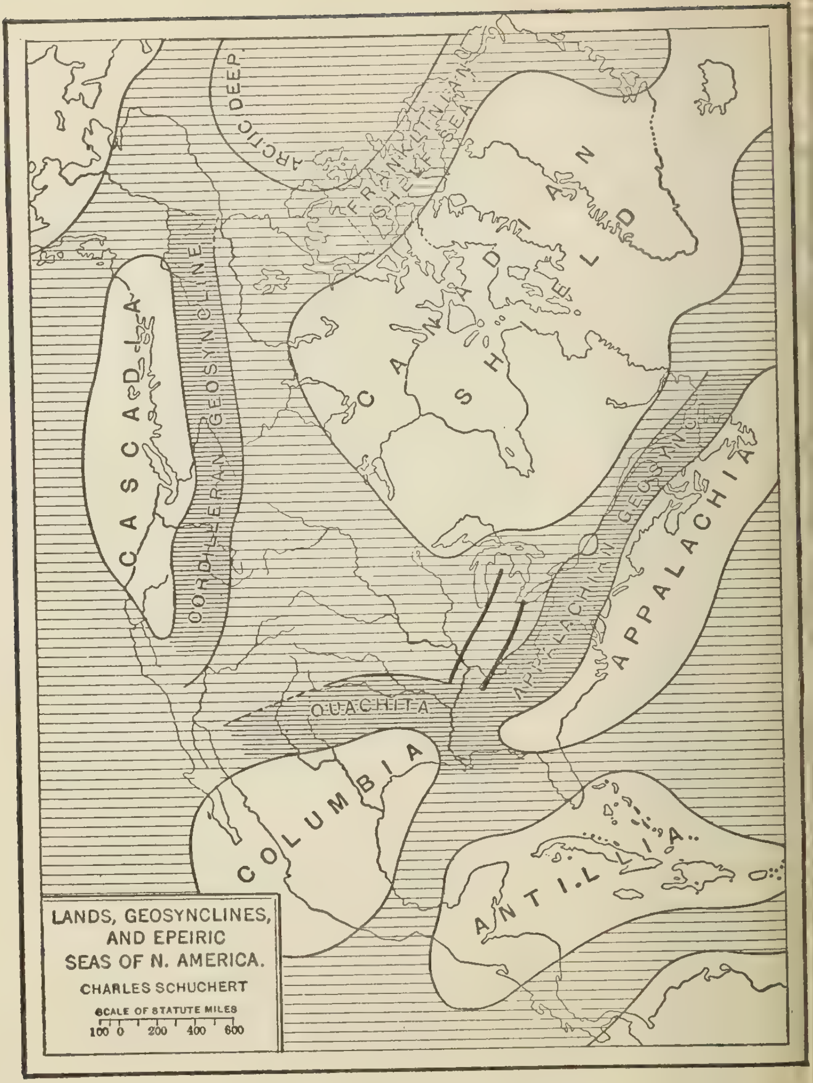


Fig. 9.—Generalized map of North America in Paleozoic time, showing in white the lands or positive elements, in darkest shading the three geosynclines or sub-positive elements, and in lightest shading the extensive neutral medial area of the continent. The two heavy black lines indicate the Cincinnati and Ozark (Kankakee) uplifts. From the Pirsson-Schuchert "Text-book of Geology," published by John Wiley & Sons, Inc.

though a very low form of water-living alga appears to have been present. Even if we exclude the probable fossil evidence, the presence in Ontario of 18 miles of sediments, of which about one-half is impure limestone along with much graphite, indicates unmistakably that life was already in existence. As we are treating of the oldest known time in the history of the earth, this is the place to emphasize what results were then attained and what natural processes were at work.

At the very beginning of the Archeozoic era, the earth had a rocky and fairly stable exterior known as the lithosphere, an atmosphere and a hydrosphere; protruding continents, and oceanic basins that were filled with slightly saline water; twice-daily tides, wear and tear of the ocean waves against the lands, reduction of the high lands by the atmosphere, and, through the rains, washing of the soil and solution materials into the seas and oceans. The sun shone then as now and made life possible, and the man in the moon was as clearly developed as he is today, remaining so ever since because this satellite has had neither atmosphere nor water to wash away his face. We therefore see that the earth was then very much as it is now, with these great differences, that at first the atmosphere was almost devoid of free oxygen and probably richer in carbon dioxide, that the lands were not covered with verdure, and that what there was of life was of a very low order and most prevalent in the oceans though there undoubtedly was some also on the lands.

Then follows the second era of geologic time, the *Proterozoic,* with a thickness in south-central Canada of nearly 20 miles of coarse sediments almost devoid of fossils, and 4 miles of lavas. Probably as much as one-half of this mass is of fresh-water and volcanic origin, the rest being of marine and brackish-water origin. In the Rocky Mountains there are upwards of 7 miles of less coarse sediments that include about 1.5 miles of probable marine limestones. In this connection it should also be noted that one of the remarkable recent discoveries in geology is that we know very little of marine Proterozoic sediments (in the sense of marine and fossiliferous Paleozoic formations) and that there is as yet even no hint as to where the life of the Cambrian originated.

The Archeozoic and Proterozoic eras have the most ancient strata of the earth and their combined thickness is 40 miles as against about 50 miles (maximum thickness) for all subsequent, fossiliferous strata. In this we discern the astounding fact that about two-thirds of geological time and the greater part of the earth's history had passed before organisms became sufficiently endowed with hard parts to be abundantly preserved as fossils in the sedimentary rocks. Also, the small thickness of the sediments when contrasted with the much thicker ones of later time indicates how little of the ancient history has been recovered by geologists. It likewise means that the evolution of life for an incredibly long time was exceedingly slow in rising from the simple unicellular forms into the multicellular forms of plants and animals. It may be that the Archeozoic was entirely occupied in originating only the unicellular plants and animals. In the Proterozoic, organic differentiation appears to have gone on faster, because at the very beginning of the Paleozoic era are found all of the main kinds of marine animals other than fishes.

The third era of geologic time, the *Paleozoic,* is based upon a thickness of about 4.75 miles of muds and sands and 3.4 miles of limestones. These thicknesses are in the Appalachian region, and form one of the most complete of all known Paleozoic records. In the Cordilleran area, where the record is far less complete, there are about 2 miles of coarse deposits and 3 miles of limestones. Toward the medial regions of the continent the thick lateral sections thin down to about 1 mile, essentially of limestones. The maximum thickness of Paleozoic strata in all parts of the continent rises to 12 miles for detritals and 9 miles for limestones.

Shortly after the opening of the Paleozoic appear the fishes, the first of the vertebrates, and now, surprising as it may seem, in the fresh waters of the land and not in the seas. Before half of the Paleozoic is gone, double-breathing is perfected, and the amphibia begin to people the dry lands, and long before the close of the era give rise to the reptiles. It is also in the middle Paleozoic that the most primitive forests arise, and not long afterward, in the Coal Measures, their remains, falling into great swamps, create the world's greatest supply of fuel in the soft and hard coals (see Fig. 10).

The fourth era, known as the *Mesozoic,* has, in western North America, about 7.5 miles of sediments, of which not more than 1.25 miles are limestones. On the other hand, in the lands bordering the Gulf of Mexico and chiefly in Mexico there are less than 3 miles of Mesozoic sediments, but here the limestones make up more than one-half of the total thickness. Throughout the continent the maximum thickness of Mesozoic sediments rises to 15 miles for detritals and 1 mile for limestones.

The Mesozoic is the Age of Reptiles, and yet the little mammals and the toothed birds are storing up intelligence and strength to replace the reptiles when the cycads and conifers shall give way to the higher flowering plants. Then follows the *Cenozoic* era, the Age of Mammals, with a thickness in California of about 5 miles of coarse sediments, contrasting with about 4 miles of fresh-water detritals in the Rocky Mountain area, and in these rocks occurs a most wonderful array of modernized animals. The maximum thickness of Cenozoic strata in all parts of the continent totals 13 miles of detritals. The era closes with a very decided glacial climate and another marked change in the animal world, out of which man rises to his present primacy among organisms. Geologists therefore call the present time the Psychozoic era or the Age of Reason.

Relative duration of the eras. The preceding table gives the generalized thicknesses of the sedimentary rocks of North America in terms of the detritals (muds and sands) and the solution materials (limestones and dolomites). To attain more clearly the relative duration of each of the eras it is desirable to restate the probable time taken by the far more

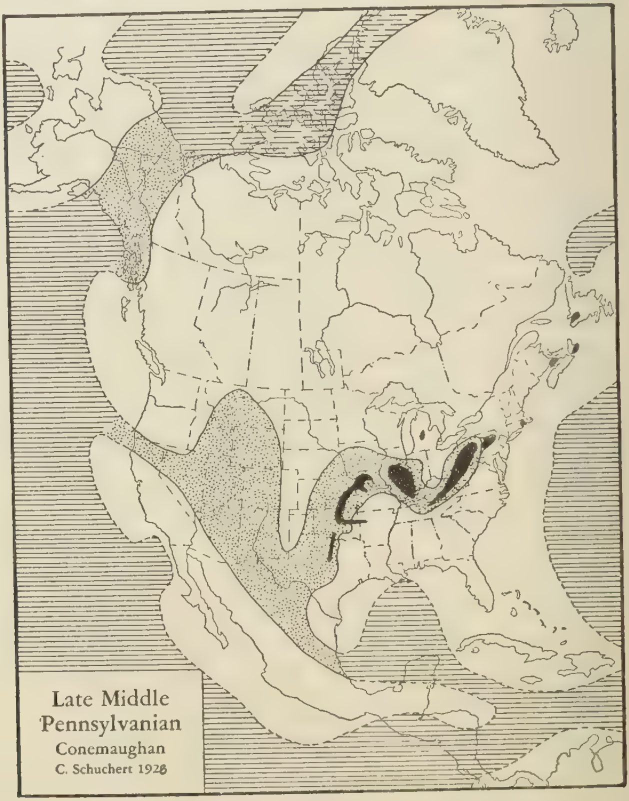


FIG. 10.—The marine inundation of middle Pennsylvanian time, showing the coal-making areas of this period in solid black. While the coal is being made, these swamps are just above sea-level and have fresh water; they are repeatedly invaded by the sea, only later to become low lands accumulating plant débris or peat. Today the coal beds are superposed one above another and separated by either fresh-water or marine muds and sands.

TABLE OF MAXIMAL SEDIMENTARY ACCUMULATION IN NORTH AMERICA

Eras	Thickness and nature of deposits	Equivalent in muds and sands (Ls. x 4)	Percentage of geologic time on sediments and breaks (Total 1600 million years)	Ratios on basis of uranium. From Barrell 1917	*Ratios and percentages of older authors*			
					Dana 1874	Williams 1893	Walcott 1893	Haughton 1878
Cenozoic	13 miles coarse detritals	13	4	4	1 (3%)	1 (3%)	2 (5%)	23%
Mesozoic	15.5 " muds-sands 1 " limestones	19.5	8	11	3(10%)	3 (8%)	5(13%)	
Paleozoic	12 " muds-sands 9 " limestones	48	22	30	12(37%)	15(39%)	13(32%)	43%
Proterozoic	19 " coarse detritals 0.5 " limestones	21	24	55	(?50%)	(?50%)	(?50%)	34%
Archeozoic	11 " muds-sands 9.5 " limestones	49	42					
Totals	90.5 " of known sediments	150	100	100				

slowly accumulating solution materials in terms of those of the detritals. Geologists differ greatly as to the time required to deposit any kind of sediment, but most of them will agree that limestones, other than those of reef origin, take at least four times longer than the coarser materials. On the other hand, the rate of deposition is exceedingly variable from place to place and from time to time. Further, the limestones of pre-Cambrian time are on the average far less pure than those of the later eras. Accordingly, on the basis of per annum rate of sedimentary accumulation there are as yet no reliable estimates, and besides we are just beginning to appreciate that the geologic record is very incomplete.

Recently the writer has brought together all the maximum thicknesses of the known formations in North America, and on these and other data has calculated in several different ways the probable duration of geologic time. He was surprised to learn that on this basis, and allowing liberally for the probable duration of the great breaks between the eras, his results, stated in years, agree fairly well with those attained from uranium disintegration. These results translated into percentages are given in the fourth column of the foregoing table. At present the most reliable standard for calculating the duration of geologic time is that of the rate of disintegration of radioactive minerals, which indicates that the age of the earth since sediments began to form is of the order of 1500 million years.

Now let us compare the above results with the ratios obtained by other geologists, but before doing so it should be said that their statements relate almost always to post-Proterozoic time. If, however, we follow Dana's ratios, it is clear that he held in his famous text-book that about one-half of geologic time lies back of the Cambrian. It is on this basis that their figures are given in the previous table. The figures in parentheses restate the ratios in percentages of all geologic time.

Periodic reëlevation of the lands. We have thus far presented the sedimentary evidence in the main as if it had continuously and regularly formed, without stoppage or "breaks." The geologic record, however, was not laid down in this way, because the surface of the earth does not remain stationary. Even though to humanity the "everlasting hills" appear to be permanent features of the earth's surface, they are all doomed to be carried away by the rain and transported by the rivers into the seas and oceans. Erosion of the land goes on until all is worn to near sea-level, and then there is but a very sluggish run-off of the rain that falls upon the planed continents. The earth has repeatedly had such a low relief; in fact, this has been the condition during the greater part of its history.

The continents are repeatedly reëlevated in relation to the strand, and this goes on many times in a small way and less often on a large scale (see Fig. 3). We have said that in the course of the geologic ages the earth has shrunk at least 200 and possibly 400 miles in diameter. The earth is still shrinking all the time, and this gives rise on the surface to small warpings whose difference of elevation is usually not more than a few hundred feet. These are but surficial symptoms, due to internal readjustment, remarkable as it may seem, in an earth as rigid as steel—local accommodations of the earth's mass to loss of heat and molecular rearrangements. These alterations finally set up strains in the lithosphere which are too great for its strength to bear, and then there is a time of breaking and greater readjustment between the relatively settling and rising masses. At these times ranges of mountains are slowly raised up near the margins of the continents, due to the shortening, folding, and breaking of the earth's crust, and the ranges have lengths of between 1,000 and 1,500 miles. These are the minor shrinkage movements, the "disturbances," which are coming more and more to be regarded as the basis for dividing the eras into periods of time, and how often they occurred is one of the things that geologists are trying to ascertain. In North America we know of at least eight of these minor crustal readjustments, but in all the world there are many more than this.

Finally, there comes a time of major shrinking that adjusts all of the strains and stresses set up in the earth's mass by the minor, incompletely adjusted shrinkages. The earth has just passed through one of these major readjustments, and accordingly we see all of the continents standing far higher above sea-level than has been the rule throughout geologic time, and in many of them rise majestic ranges of mountains (see Fig. 3). A grander, more diversified, and more beautiful geography than the present one the earth has never had; this statement is made advisedly and with the knowledge that our planet has undergone at least six of these major readjustments of its mass. These greater movements are the "revolutions" that close the eras. Because the lands are then high they are subject to more active erosion and in the last analysis all of the broken-up detrital and dissolved material is carried away by the streams to the oceans. At these times the continents are also largest and the materials received by the oceans are laid down on the outermost edges of the lands, where subsequent transgressions by the sea cover and hide them from our observation. After a long time the sea again comes to press further and further upon the land and spreads more formations of stratified rocks over those left by the previous floodings, the older geologic formations (see Fig. 11). Therefore there is upon the present continents between each two such successive eras a "great break" in deposition, a hiatus in the geologic record, a "time interval" when no record other than erosion is at hand. These "breaks" in sedimentation are representative of loss of record and are called "intervals"; they are regarded as the closing times of the eras.

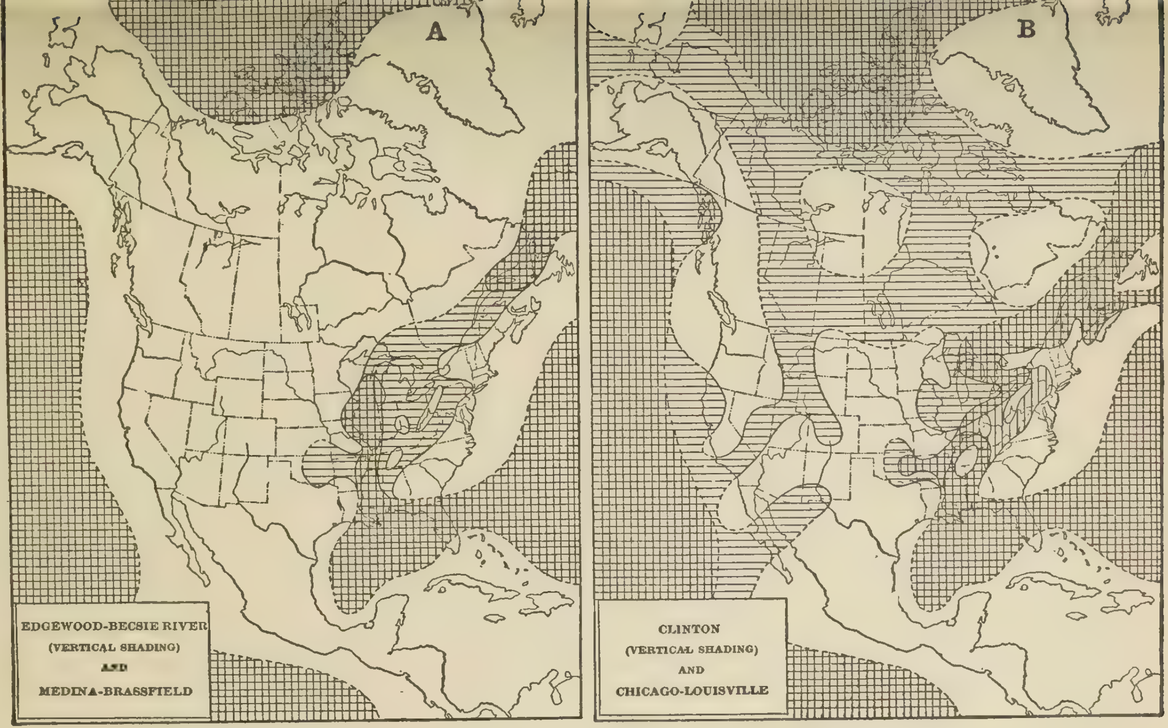


FIG. 11.—Earlier and maximal phases of the Silurian flood. From the Pirsson-Schuchert "Text-book of Geology," published by John Wiley & Sons, Inc.

During these intervals when the continents are highest and largest, the oceans are smallest in areal extent, the separate continents are often united by land-bridges as Panama unites the Americas, such bridges alter the direction of the great ocean streams like the Gulf Stream, the high mountain ranges alter the directions of the air currents and take out of them their moisture so that great desert areas arise like our inter-Rocky Mountain country, and because of these vast changes nearly all of the major movements are accompanied by glacial climates. Such mighty changes in the geography, topography, and climate of the earth react strikingly upon the life of the polar and temperate belts and so disarrange it that the major "intervals" following "revolutions" are spoken of as the critical times in the earth's history—critical not only for the geography, separating or uniting continental masses, but also for life, since as a result of the lands then becoming high and cool to cold in places and elsewhere moist or dry, vast domains of organisms are forced to adapt themselves to the altered conditions, or to migrate into more favorable areas, or to die out and make room for the rising hordes of fitter types.

In this way cycle after cycle of organisms appear and vanish, and their coming and going is brought about by the changing environment. Thus in the Mesozoic era, we see the lands mastered by the cycads and conifers among the plants and the dinosaurs among the animals, the air by the flying dragons, and the seas and oceans by other reptiles and hordes of ammonites and squid-like molluscs. The Great Reaper then steps in and through struggle and the elimination of countless organisms, resulting in regressive and progressive evolution, the lands in the Cenozoic begin to bloom with cereals and fruit-bearing flowering plants and grand hardwood forests, the atmosphere is scented with sweet odors, a vast crowd of new kinds of insects appear, and the places of the once dominant reptiles of the lands and seas are taken by the mammals. Out of these struggles there rises a greater intelligence, seen in nearly all of the mammal stocks, but particularly in one, the monkey-ape-man line. Brute-man appears on the scene with the introduction of the last glacial climate, a most trying time for all things endowed with life, and finally there results the dominance of reasoning man over all of his brute associates.

The Cenozoic era was a time of especially marked geographic alteration, as is especially attested by the evolution and spread of the elephant stock or Proboscidea. These animals arose in Africa early in the era, but there was no means by which they could spread into other continents, because Africa remained isolated. At about the middle of the Cenozoic, the Alps were rising and these crustal alterations also gave birth to a land-bridge across the Mediterranean connecting Europe and Africa. Across this bridge the long-faced elephants, now all gone, spread first into Europe and thence into Asia. A little later much of Asia began to rise, and the culmination is seen in the grandest of all mountains, the present Himalayas. These alterations permitted the elephant stock to spread across Asia and the Nome bridge into Alaska and wider North America, and they had no sooner arrived there than they were on their way across the newly arisen Panama bridge, thence to spread all the way south into distant Argentina. North America was then peopled with many kinds of camels and horses, and they, along with many other animals, migrated into South America. Wanderlust was upon the world, and from South America there migrated into our country great sloths, a claw of one of which was found by Thomas Jefferson in Virginia, and described as that of a huge lion. The great Democrat may be excused for his error, since in those days fossil sloths were unknown in North America; rather should he be praised, for he is the only president who has described a fossil, other than live ones!

Times of volcanic activity. In all that has been said we see the periodic rejuvenation of the lands and the renewal of active erosion. During these times of crustal unrest and subsequent internal readjustment the molten portions deep down in the lithosphere are forced to rise as great hot tongues into the cores of the mountain ranges, and in many places they break through and give rise to active volcanoes. Beneath lie great and highly heated masses that subsequently cool into granitic rocks, and when long afterward the mountains are worn away we discern among their roots these cores of granite. However, during all the time of crustal rising and readjustments the volcanoes are more or less active, spewing violently or quietly into the atmosphere tremendous volumes of rocks blown into volcanic ashes and of lavas, and great quantities of gases that increase the volume of the atmosphere; and much juvenile water is added by them and the thermal springs to the previous water of the hydrosphere. Even though the lithosphere absorbs much old water through soaking and mineralization, the oceans are yet constantly growing in volume through this accession of juvenile water. In the same way, even though vast quantities of carbon are taken out of the atmosphere by organic agency and buried in the rocks, there to be transformed into natural gases, petroleum, asphalt, peat, and coal, the air is periodically resupplied by the volcanoes and by the hot-water springs.

Periodic spreading of the oceans. So far we have been describing the alterations that take place in the dry land; let us now turn to the realms of Neptune and note briefly the areal fluctuations of the oceanic waters during the latter half of geologic time. The geography of the earlier times we have not as yet deciphered and therefore cannot relate the movements of the oceans. It has been stated that when the earth shrinks, the lands rise in relation to the strand-line, and that this is especially true at the times of major crustal alterations. It is now definitely known that at the close of all the eras the continents were largest and at some of these times were even larger than they are now. On the other hand, the present oceans are more than full and for some time have been spilling over the outer edges of the continental platforms, apparently to the extent of nearly ten million square miles or about 5 per cent of the earth's surface. In other words, the present continental platforms occupy 35.5 per cent of the lithosphere, while the total water areas are equal to 69.6 per cent of the earth's surface.

The mean height of the present continents above the sea is given by Sir Archibald Geikie as about 2,400 feet, and if these protuberant masses were deposited in the sea, as they surely will be by the future rivers, the ocean waters would be displaced to the extent of raising the strand-line about 650 feet. We see therefore that the ocean level is also inconstant, and accordingly, even though the North American continent should remain stationary, about half of it would be covered by the displaced seas to depths of several hundred feet.

Between the comparatively short intervals of mountain making and crustal unrest occur the long quiet times of erosion when the lands are planed down to near the sea-level. This transference of rock leads, as has already been stated, to more or less flooding of the continents by the oceans (see Fig. 12). During the Paleozoic, Mesozoic, and Cenozoic eras, North America, and especially the United States, was widely flooded by warm and shallow marine waters at least sixteen times—Waucobian, Croixian, Canadian, Chazyian, Mohawkian, Cincinnatian, Silurian, Devonian, Mississippian, Pennsylvanian, Permian, Triassic, Jurassic, Lower and Upper Cretaceous, and in an oscillatory and marginal way during the Cenozoic (see Fig. 13). These shallow-water spreadings begin in a small way, grow to greater dimensions throughout a very long time, and then, declining, recede more rapidly than they came (see Fig. 11). They vary in areal extent up to 4,000,000

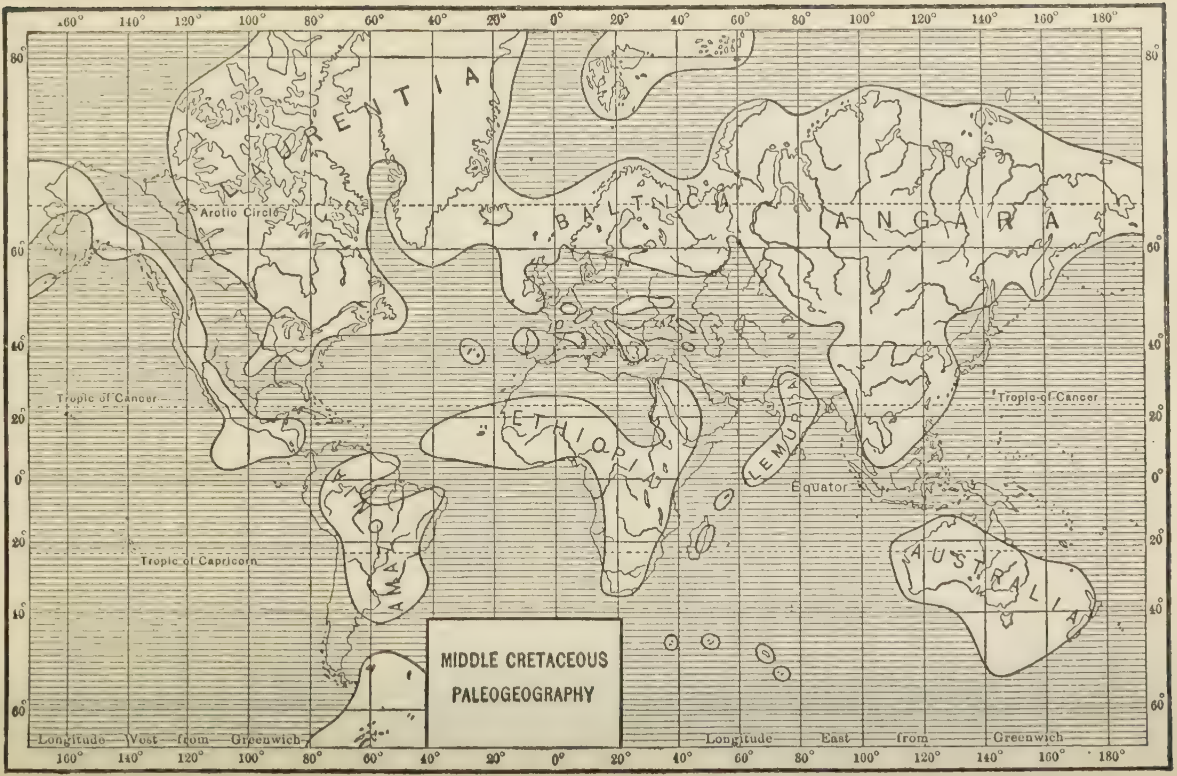


FIG. 12.—Great Middle Cretaceous transgression of the oceans over the lands. In the main after De Lapparent. From the Pirsson-Schuchert "Text-book of Geology," published by John Wiley & Sons, Inc.

square miles. The greatest floods have spread from the Arctic Ocean, others from the Pacific, and those of least amount from the Atlantic. On the other hand, the number of floods was greater from the south than from the north, and the waters were most persistent in the Appalachian, lower Mississippi, and Rocky Mountain areas. Where the greatest thicknesses of sediments accumulate, out of this continental débris there will arise, phœnix-like, a future mountain range. After about 40,000 feet of strata had been deposited in the Appalachian trough, there arose near the close of the Paleozoic era the majestic Appalachian Mountains, some of which may have towered to at least 20,000 feet above the sea. In fact, the original mountains were destroyed by erosion during the Mesozoic era and the reëlevated Appalachians of today are due to later uplifts of more than 2,000 feet; subsequent erosion has developed them into their present interesting forms. Today one may travel comfortably over the roots of these once grand mountains by way of the Pennsylvania, the Baltimore and Ohio, and the Chesapeake and Ohio railways.

Areal variability of organic habitats. We have seen that the dry lands become alternately larger and smaller, and in the same way the shallow-water areas of the oceans are vastly increased when they spread over the lands, and are again greatly decreased when the land areas increase in size. Thus when the lands are widely flooded there is a great increase in the quantity of marine life, but little is originated that is new, while on the lands the climate becomes insular, warm and moist, and productive of the greatest amount of life in the then restricted areas. On the other hand, when crustal readjustments occur, the lands are largest, driest, and coolest, and these changing environments react on the life and bring about great alterations in the composition of the floras and faunas. At these times the shallow-water marine areas are smallest and most variable in turbidity and salinity—conditions that

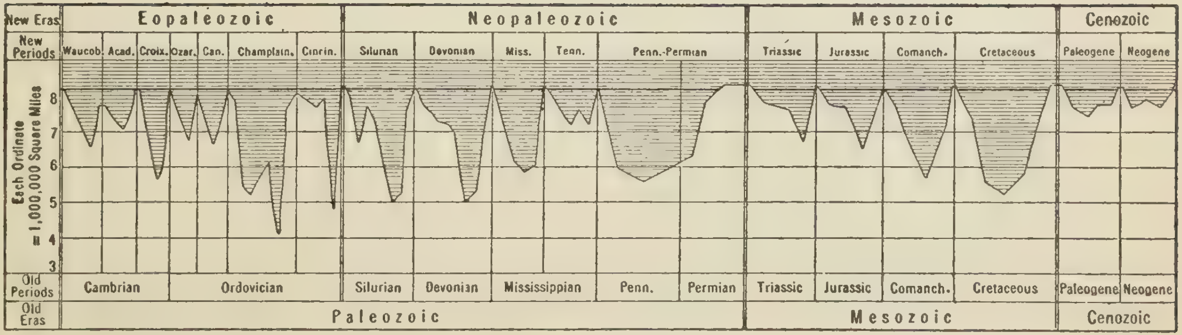


FIG. 13.—Diagram showing time and extent of the known floods that have inundated North America since the close of the Proterozoic era.

set up renewed evolution, resulting in the rise of new stocks. In these various periodic physical changes we see the stimulus that quickens organic evolution. Each cycle begins and closes with a comparatively short time of accelerated evolution, while the far longer intermediate tranquil periods lead to but little that is striking in the way of new organisms.

Conclusion

From this summary of the earth's changing surface and climate during geologic time the following facts may be selected for emphasis:

First, geologic time is very, very long, indeed so vast as to be beyond human comprehension. No geologist today thinks that the evolution of the earth and its life could have taken place in less than 1000 million years. In all of this we perceive how slowly the physical and organic processes bring about the results of nature. *Second,* the constant shrinking of the earth leads to an instability of surface that brings about periodic changes, not only in the areal space relations of the water and land, but in the shapes and heights of the lands as well. *Third,* no sooner are the lands elevated above the sea-level than the weathering processes become more active and through the agency of the rain and wind all high places are, according to human standards, slowly but surely moved into the seas and oceans. *Fourth,* as a result of the transference of the high lands into the water areas the latter are to a certain extent displaced and periodically flood more or less of the lands. *Fifth,* due to these surficial changes the atmosphere and the climate are constantly changing in a small way, but every now and then when the lands are largest, highest, and driest, a cold period appears and disarranges the entire organic world, both on the lands and in the waters. *Sixth,* when these "critical periods" are upon the world, the face of the earth is scenically grand and beautiful and at the same time the struggle for existence among the living is most intense. The rulers of the various domains find themselves overtrained and overspecialized, and succumb one after another to the changing environment. Their places are taken by the small, less specialized, and heretofore little known stocks, which quickly adapt themselves to their environments and become the dominators of the organisms about them. In all of this unceasing organic struggle most of the unadaptive families fail to continue; others are pushed by the pulse of life into the less desirable places, where they continue to exist as the static forms—the living fossils that tell us so much that is most interesting of once prominent stocks of plants and animals; but at all times much of life quickly responds to the changing environment and is remolded into the more fit, active, and alert types. The experiences thus gained are passed on to successive generations, and so the organic world as a whole advances to ever better living mechanisms endowed with higher and higher mentality.

The greatest mentality in the sea has been repeatedly derived from the continents, first in the fishes, then in the reptiles, and lastly in the mammals, and they have adapted themselves to the sea because of the ease with which they can there prey upon the less alert and intelligent. Such adapted stocks in the course of geologic time grow larger and larger, as, for instance, the whales of today. Out of them, however, comes no higher mentality. They represent an adaptation in the wrong direction, that is, to an easier life, for the highest organisms with the greatest mentality have been developed only on the land where the struggle for existence is fiercest because of the constant necessity of adaptation to an environment subject to intense changes. Organic supremacy is attained only through constant vigilance.

CHAPTER III

THE ORIGIN OF LIFE

LORANDE LOSS WOODRUFF
PROFESSOR OF PROTOZOOLOGY, YALE UNIVERSITY

The conception of a common basis of all vital activities—that all living nature is one—was the culmination of a long series of researches during the first half of the nineteenth century, and forms the corner-stone of modern biology. At the present time biology is the study of the properties of this physical basis—an inconceivably complex physicochemical organization called protoplasm—because to it, in the last analysis, the multifarious activities of animals and plants must be referred.

PROTOPLASM

Since we are only familiar with life as a manifestation of protoplasmic activity, the problem of the origin of life naturally resolves itself into the problem of the origin of protoplasm, and it is obviously impossible to discuss the origin of living matter without an insight into its composition and organization. The crude attempts of the alchemists of the Middle Ages to produce artificially in crucible or retort an homunculus complete, though they had not the slightest conception of its composition, affords, in contrast with the present trend of intensive analysis of protoplasm, a vivid illustration of the progress of scientific method in the interim. Obviously, analysis must precede synthesis even though the latter may never be achieved.

From one point of view it is impossible to analyze protoplasm because the least disturbance of its fundamental organization results in a cessation of those phenomena characteristic of life, leaving matter in the non-living state before us. However, since in the transformation of matter from the living to the lifeless condition there is certainly no loss of weight, it follows that the complete material basis of protoplasmic organization remains for examination, and we may assume, as a working hypothesis, that the properties of protoplasm are a resultant of the properties of its constituent elements. But it may be noted in passing that an analysis of the débris from a destroyed factory probably would give one very little insight into the *modus operandi* of the intact organization.

Physical characteristics of protoplasm. Since the fundamental activities of all forms of protoplasm are of the same nature, biologists have naturally tried to discover a corresponding fundamental physicochemical basis in all living matter, and thus far research, broadly speaking, indicates that such exists. Living protoplasm ordinarily appears under a moderately high power of the microscope as a viscid, granular fluid. When studied with the highest magnifications, usually after being killed and stained, it often exhibits an extremely complex structure which, however, cannot be briefly described, as it is subject to considerable variation not only in the protoplasm of different organisms and tissues, but in the same microscopic unit mass under varying physiological conditions. Most frequently, though, it seems to present a foam-like appearance, due perhaps to closely crowded minute drops of a liquid alveolar substance suspended in a continuous interalveolar substance, also liquid but of a different physical nature. But it seems clear, since studies of protoplasmic structure have revealed by no means a complete correlation between its morphological organization and its activities, that the key to the latter must lie in an ultra-microscopic architecture whose varying phases are, as it were, reflected in the changing picture which the microscope is capable of resolving.

Chemical characteristics of protoplasm. Chemical analysis shows that protoplasm is a colloidal complex comprising chiefly the elements carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, sodium, chlorine, iron, and magnesium—all of which are commonly found in the inorganic world. Indeed, there is no chemical element present which is peculiar to living matter.

But there are *combinations* of elements which are distinctly characteristic of protoplasm, not being found in nature except as the result of protoplasmic activity. These chemical combinations are the proteins, carbohydrates and fats, and of them the proteins are the most significant because they are universally present as a part of all living matter and form quantitatively its chief organic constituent. Proteins invariably consist of the elements carbon, oxygen, hydrogen, nitrogen, sulphur, with sometimes phosphorus or iron; the nitrogen, however, particularly distinguishing them from the other organic compounds of the living complex. Although the stereochemical composition of a protein molecule has not been determined, analyses show that it may be split up into a large number of simpler, though still very complex molecules, and it is evident that its few elements may be represented by hundreds and even thousands of atoms. As Underhill has said: "Viewed from the chemical standpoint protein is seen as a huge molecule, complex in structure, labile in character and therefore prone to chemical change. So large and intricate is the make-up of the molecule that chemists for generations have been baffled in their attempts to gain any adequate conception of its nature. At the present stage of our knowledge it is impossible to form any satisfactory definition of a protein based either on its chemical or physiological properties."[1]

---

[1] Underhill, F. P., "The Physiology of the Amino Acids," 1915, published by Yale University Press.

It must suffice then to emphasize that it is the presence of proteins and the power of forming them which is the diagnostic chemical characteristic of matter which is alive. It will be recognized, of course, that proteins are not "alive," and even if the biochemist should succeed in artificially synthesizing a protein, which has not thus far been accomplished, by grouping together amino acids, which already have been made synthetically, this would not be in any sense the artificial production of life. But since proteins are the one molecular system of which we are aware which is diagnostic of protoplasm, we have the right to assume, for the present at least, that they represent in a way the quintessence of that arrangement of matter which exhibits life, while clearly recognizing that they are but an integral part of the more complex, physicochemical structure of protoplasm. Protein is, as it were, "the chemical nucleus or pivot around which revolve a multitude of reactions characteristic of biological phenomena."

The agent of vital manifestations is thus clearly a physicochemical complex and one of its most conspicuous and fundamental phenomena is what has been described as "energy traffic" or the function of trading in energy. This consists in appropriating energy from the environment, storing it in a state of higher potential and later expending it in the kinetic form. The lability of many of the molecular aggregates of protoplasm, that is, their tendency to change in composition toward greater or less complexity, coinciding with deoxidative and oxidative processes, is an important characteristic and one which endows the protoplasmic system as a whole with its perennial plasticity—"its peculiar proneness to change its composition under the stimulus of slight changes in the energy-equilibrium between itself and its surroundings."[2]

Definitions of life. This continual flux, which is now emphasized as characteristic of protoplasm, was recognized as a characteristic of *organic individuals* long before it was recognized in their physical basis, and is expressed in nearly all definitions of life. Aristotle described life as "the assemblage of the operations of nutrition, growth and destruction"; Bichat as "the sum total of the functions which resist death"; De Blainville as "the twofold internal movement of composition and decomposition, at once general and continuous"; Lewes as "a series of definite and successive changes, both of structure and composition, which take place within an individual without destroying its identity"; while Spencer defines it as "the definite combination of heterogeneous changes, both simultaneous and successive, in correspondence with external coexistences and sequences" and as "the continuous adjustment of internal relations to external relations."

---

[2] Allen, F. J., "What is Life?" Proc. Birmingham Nat. Hist. and Philos. Soc., vol. 11, pp. 44-67, 1899.

Obviously these statements are far from satisfactory, but no adequate, concise and yet comprehensive definition of life ever has been formulated, though it has been essayed by the best minds for generations. The fact is that life is too complex to be described concisely, and so unique that it is impossible to resort to the lexicographer's trick of comparing it with something else. Although many physicochemical phenomena contribute to life, not one of them will serve as a criterion and all of them collectively do not offer, as yet, a satisfactory explanation. Whether behind the physical phenomena there are intangible metaphysical factors is a question outside the realm of biology. Since the limitations of our senses confine our perception to that part of our environment, perhaps a very small part, denoted by the fundamental concepts of science—matter and energy acting in space and time, we are forced to interpret, in so far as we are able, the life processes in these terms. Thus far, however, the study of protoplasm has given no reason for abandoning the productive *working hypothesis* that life phenomena are an expression of a complex interaction of physicochemical laws which do not differ fundamentally from the so-called laws operating in the inorganic world.

Individuality of organisms. We have seen that, although all protoplasm has a similar fundamental physicochemical basis, nevertheless there is a considerable, indeed a great, diversity in the minor details of its composition, not only in different species of animals and plants, but also in the various parts of the same animal or plant. In fact, organisms are *organisms* because of specific local differentiations in the immediate substratum of their vital activities.

This specification of protoplasm is rendered possible by the fact that the structural units of all organisms are microscopic masses of protoplasm, termed cells.[3] The bodies of all higher animals and plants are congeries of millions of these protoplasmic units, while many of the simpler forms of life consist of but a single one. Therefore it is apparent that a fundamental characteristic of organisms as we know them today is not only that the material basis of their activities which we call life is the somewhat protean, though no less real, protoplasm, but also that this physical basis is individualized into structural moieties, the cells. It is not an overestimation to say that the recognition of this dual similarity of physicochemical and morphological organization of all living things must be considered the greatest single generalization which biological science has attained, and must be ranked with the theory of organic evolution, of which it is the corner-stone, in its far-reaching bearings.[4]

---

[3] Wilson, E. B., "The Physical Basis of Life," New Haven, 1923.

[4] Minchin, E. A., "The Evolution of the Cell." *Amer. Nat.*, vol. 50, 1916, pp. 5-38, 106-118, 271-283.

Conklin, E. G., "The Basis of Individuality in Organisms from the Standpoint of Cytology and Embryology." *Science*, new ser., vol. 43, 1916, pp. 523-527.

Driesch, H., "The Problem of Individuality," 1914.

Obviously, then, the biologist in dealing with living substance has it only in the form of cells, and these, singly or colectively, constitute individual organisms. Thus in the final analysis protoplasm is known to us only in the form of living ndividuals, and the expressions "protoplasm" and "life" are merely abstractions; one indicating that all individuals have to a certain extent a common organizational foundation and the other that they exhibit certain characteristic actions and reactions. The living organism is a microcosm which exhibits a permanence and continuity of individuality correlated with specific behavior, and this it transmits to other matter which t makes a part of itself and to its offspring in reproduction.

It is apparent that the phenomena which we call life are dependent upon the interplay and interchange between the highly organized protoplasmic complex and its environment. Although the organism, whether animal or plant, is an individual, still it retains its individuality—lives—solely by its powers of developing and maintaining exquisite adjustments to ts surroundings, and therefore the concept protoplasm has ittle or no content unless environmental relations are included. This fitness of the organism, as Henderson has recently emphasized, is but one part of a reciprocal relationship of which the fitness of the environment is the other. "The fitness of the environment results from characteristics which constitute a series of maxima—unique or nearly unique properties of water, carbonic acid, the compounds of carbon, hydrogen, and oxygen and [for primordial life] the ocean." "No other environment consisting of primary constituents made up of other known elements, or lacking water and carbonic acid, could possess a like number of fit characteristics" for protoplasmic phenomena. The properties of matter and the course of cosmic evolution are intimately related to the structure of the living being and to its activities. Indeed, "the whole evolutionary process, both cosmic and organic, is one, and the biologist may now rightly regard the universe in its very essence as biocentric."[5]

History of the Establishment of Biogenesis

The origin of this environment on the earth having been previously considered, we may turn now to the question of the origin of life—that primeval question which has been asked by all ages, and the answers to which, if they do no more, at least epitomize the philosophic and scientific perspective of the times.

One of the greatest intellectual characteristics of the Greeks was their scientific curiosity, and therefore it is not strange that the first biological question which they propounded was in regard to the origin of life. Even to the best minds of the ancients there was little incongruity in the idea of animals and plants arising *de novo* from earth or water. Although Aristotle, whose scientific studies formed the foundations of natural history, devoted a great deal of thought and ingenuity to the subject of the origin of animals, he apparently accepted with little reservation the statements that even such highly developed organisms as worms, insects, and some fishes could come into being from mud. Such ideas are voiced over and over again through more than twenty centuries by philosopher and poet, theologian and layman.

Lucretius, in his *De rerum natura,* says that "with good reason the earth has gotten the name of mother, since all things are produced out of the earth, forming in rain water and in the warm vapors raised by the sun." Virgil in the fourth *Georgic,* which is devoted to a discussion of bees, graphically describes a simple method used in Egypt for obtaining bees from the dead bodies of bullocks.

Coming to the mediæval period and later we find Cardan stating that water engenders fishes and that various types of animals arise from fermentation. Swan in his *Speculum mundi* ays that a dead horse breeds wasps, a mule produces hornets, vhile from an ass arise bumble bees. Van Helmont, one of he founders of chemical physiology, gives particularly specific irections for the experimental production of scorpions and nice, while Kircher actually figures animals which he avers rose under his own eyes through the influence of water on he stems of plants; an instance, perhaps, not of spontaneous eneration but of the transformation of plant into animal, vhich was also a notion prevalent at the time. The ironical eflections of one Ross, aroused by the scepticism of Sir homas Browne in regard to mice arising by putrefaction, are uite typical of seventeenth-century opinion. He says: "So ve may doubt whether in cheese and timber worms are gen-rated, or if beetles and wasps in cow-dung, or if butterflies, ocusts, shellfish, snails, eels, and such life be procreated of utrefied matter, which is to receive the form of that creature o which it is by formative power disposed. To question this s to question reason, sense, and experience. If he doubts his, let him go to Egypt, and there he will find the fields warming with mice begot of the mud of Nylus, to the great alamity of the inhabitants."

---

[5] Henderson, L. J., "The Fitness of the Environment," 1913.

That such ideas of the origin of life were prevalent and their ruth untested by experiments is an eloquent commentary on he general state of the scientific method before the Renais-ance. It was Francesco Redi, an eminent Italian scholar, hysician, and naturalist, who, not content with tradition, but vith great faith in *observation,* made a study of the origin f maggots in decaying animal matter. By the simplest of xperiments he found that maggots never developed in meat o which flies were not allowed access and that the seeming ransformation of meat into maggots was the result of flies aying their eggs on the meat. When this was prevented, no natter how he varied the materials of his experiments, he btained the same result, and naturally concluded that the supposed appearance of life where life had not been previously was due to the introduction of foreign living material.[6]

One may imagine that the practical man of affairs, who scoffed at Redi toiling under the Italian sun with meat and maggots to satisfy a scientific curiosity, little dreamed that the practical results which germinated from this folly would be among the most important factors in twentieth-century civilization. Indeed, it is difficult to overestimate the importance of Redi's conclusion from either the theoretical or practical viewpoint, for with it was definitely formulated the theory, which has gained content and impetus as the years have rolled on, that matter does not assume the living state, at the present time at least, except under the direct influence of preëxisting living matter.

The influence of this work gradually became apparent in scholarly literature; Derham, for instance, stating that "Spontaneous generation is a doctrine so generally exploded that I shall not undertake to disprove it. It is so evident that all animals, yea and vegetables, too, owe their production to parent animals and vegetables, that I have often admired at the sloth and prejudices of the ancient philosophers in so easily taking upon trust the Aristotelian, or rather Ægyptian doctrine of æquivocal generation."[7] Another writes: "I would as soon say that rocks and woods engender stags and elephants as affirm that a piece of cheese generates mites. Stags are born and live in woods, and mites in cheese, but they both owe their being to that of other animals." And again, Henry Baker, the versatile microscopist of the Royal Society, says: "Nothing seems now more contrary to reason, than that chance and nastiness should give a being to uniformity, regularity and beauty . . . and create living animals. . . . This, however, was the opinion not only of the ignorant and illiterate, but of the most learned grave philosophers of preceding ages; and would probably still have been taught and believed had not microscopes discovered the manner how all these things are generated, and restored to God the glory of his own amazing work."[8]

---

[6] Redi, F., "Esperienze Intorno Alla Generazione Degl' Insetti," 1668. English translation by M. Bigelow, 1909.

[7] Derham, W., "Physico-Theology," 1713.

Although it is relatively easy to follow when one's eyes are opened, it is not to be imagined, of course, that one experiment, or even the long series of studies made by Redi, could annihilate a time-honored belief. Indeed, the history of the establishment of the theory extends down even to the present time, for no sooner had experiment apparently disposed of it completely than it arose again, phœnix-like, with fresh vigor in a slightly different phase demanding further study.

Among others, a Scotch priest, Turbervill Needham, studied the problem and believed that various minute organisms, which improvements in the microscope were bringing to the fore, appeared spontaneously in infusions which he boiled and corked up in flasks.[9] His results attained considerable notoriety, since Buffon, the famous French naturalist, found in them a substantiation of his theory that all organisms are aggregates of indestructible units, which upon the death of the individual are disseminated in nature and later are employed as moieties in the organization of arising generations.

Needham's results, however, were soon shown by Lazzaro Spallanzani[10] to have been obtained by inadequate sterilization and sealing of the infusions which he studied; but at this point objections came from another source—the chemists who had recently discovered oxygen and the importance of this element in the free state for the processes of life and for putrefaction and fermentation of organic matter. The treatment to which Spallanzani subjected his infusions might well have so changed the organic matter, they argued, that it was incapable of producing life. This objection was met by a series of experiments by various investigators during the first half of the last century, which showed conclusively that thoroughly sterilized infusions never developed living organisms when air was admitted which had been rendered sterile by heat or by having all suspended matter removed, while the studies of Schwann and Cagniard de la Tour intimated that fermentation and also putrefactive changes in organic infusions are themselves the result of micro-organisms.

---

[8] Baker, H., "The Microscope Made Easy," 1742.

[9] Needham, T., "A Summary of Some Late Observations upon the Generation, Composition, and Decomposition of Animal and Vegetable Substances." Philos. Trans. Roy. Soc. London, 1748.

[10] Spallanzani, L., "Expériences pour Servir à l'Histoire de la Génération des Animaux et des Plantes," Geneva, 1786.

So far it was clear that organic infusions in which no life is present do not develop living organisms except when contaminated with material from an extraneous source, which is ordinarily the atmosphere, but it remained then to be shown that living organisms are practically ubiquitous in the atmosphere and thus are available for the initiation of the microflora and fauna of infusions. This was put upon a broad empirical basis chiefly by the labors of Pasteur. Tyndall, who himself made a notable contribution to the solution of the problem by researches in experimental physics, confidently asserted that there seems to be no flaw in the reasoning, and it is so simple as to render it unlikely that the notion of life developing from dust can ever again gain currency among the members of a great scientific profession.

We thus reach the general conclusion that, so far as human observation and experimentation go, no form of life arises today except from preëxisting life. But since life is present on the earth now and the paleontological record indicates that it has been present without interruption for some hundreds of millions of years, we have to consider the following alternative: either life was transported to this planet from some other part of the universe; or life arose spontaneously from non-living matter at one period at least in the past as a natural result of the evolution of the earth and its elements.

THEORIES OF THE ORIGIN OF LIFE

It will be useless to offer any extended discussion or specific criticisms of the individual theories of the origin of life, for each one rests on many uncertain postulates, which have a greater or less degree of probability dependent, to a considerable extent, on the personal equation of the critic. It should be said, however, in justice to the authors of the theories which we shall outline, that the theories are not advanced as inal solutions of the problem of the origin of life, but rather as gropings toward a formulation of the conditions which conceivably might have attended and contributed to its genesis. The magnitude of the problem may be inferred from a recent tatement by the dean of American biologists that "the study of the cell has on the whole seemed to widen rather than to narrow the enormous gap that separates even the lowest forms of life from the inorganic world."[11]

Vitalism. The vitalistic conception that life phenomena are n part at least the resultant of manifestations of matter and energy which transcend and differ intrinsically in kind from hose displayed in the inorganic world—a denial, as it were, n the organism of the full sufficiency of known fundamental aws of matter and energy—has arisen many times in the development of biological thought, either as a reaction against premature conclusions of the nascent sciences or from an overwhelming appreciation of the complexity of life phenomena. Vitalism goes back as far as the history of science s recorded, but it attained its most concrete formulation as a doctrine during the early part of the eighteenth century, n opposition to the obviously inadequate explanations which chemistry and physics could offer for the phenomena of irritability of living matter then prominently before the professional biologist. The vitalists at that period abandoned almost completely all attempts to explain life processes on a physico-chemical basis and assumed that an all-controlling, unknown, and unknowable, mystical, hyper-mechanical force was responsible for all living processes. It is apparent, of course, that such an assumption in such a form is a negation of the scientific method and at once removes the problem from the realm of scientific investigation. No biologist at the present day subscribes to vitalism in this form; some uphold vitalism (if it must still be called vitalism) in its modern aspect, while all will undoubtedly admit that we are at the present time utterly unable to give an adequate explanation of the fundamental life processes in terms of physics and chemistry. Whether we shall ever be able so to do is unprofitable to speculate about, though certainly the twentieth century finds relatively few representative scientists who really expect a scientific explanation of life ever to be attained or who expect that protoplasm will ever be artificially synthesized. But, "In ultimate analysis everything is incomprehensible, and the whole object of science is simply to reduce the fundamental incomprehensibilities to the smallest possible number."[12]

---

[11] Wilson, E. B., "The Cell in Development and Heredity," 3d ed., 1925; "The Problem of Development," *Science*, new ser., vol. 21, 1905, pp. 281-294.

Cosmozoa theory. The establishment of the fact that, so far as we can determine, life does not arise except from preëxisting life at the present time, and the dawning realization of the intrinsic and unique complexity of the architecture of matter in the living state, which has thwarted the attempts of alchemist and biochemist to synthesize even one of its chief molecular aggregations, have led several scientists to suggest and elaborate the hypothesis that life has *never* arisen *de novo* on the earth but has been transported hither from elsewhere in the universe.

[12] Huxley, T. H., "Darwiniana." "Collected Essays," vol. 2, 1893, p. 165.

Such an idea was advanced by Richter, and later independently suggested and discussed by Helmholtz and Kelvin.[13] On the assumption that some of the heavenly bodies have always been the abode of life, and from the fact that small solid particles, which presumably have formerly been an integral part of such bodies, are moving everywhere in space, Richter pictures these particles as the vehicles which disseminate the simplest forms of life through interstellar space to find lodgment and development upon such planets as afford a suitable environment. Clearly, from this point of view, life is as old as the universe itself—living matter has never originated but has been transported from world to world. Hence the acceptance of this permanent dualism of living and lifeless matter does not answer the broad question as to the origin of life, but transfers its origin to a "conveniently inaccessible corner of the universe where its solution is impossible." However, the question before us is the origin of life upon the earth, and the plausibility of this cosmozoa theory depends on two assumptions—that life exists elsewhere in the universe and that life can be maintained during the interstellar voyage. Neither assumption has, of course, any empirical foundation whatsoever, though the second offers at least something tangible for discussion.

Many of the lower forms of life, such as the bacteria and protozoa, have the power of developing, particularly under the influence of unfavorable environmental conditions, protective coverings of various sorts about themselves and of assuming a resting condition in which all the metabolic activities characteristic of active life are reduced to the lowest ebb. In this spore or encysted state they are immune to extremes of temperature and desiccation to which they readily succumb during vegetable life. It has recently been found, for example, that certain types of bacteria can successfully endure a temperature of nearly —200° C. for six months, and about —250° C. for shorter periods, that is, a temperature considerably lower than that at which any chemical reactions are known to occur; and again the spores of other bacteria can withstand a temperature as high as 120° C. for a short time. The cysts of some relatively highly specialized protozoa can retain their vitality for at least fifty years, and the seeds of the higher plants, particularly those with a thick and impermeable integument, have been found to retain the power of germination for nearly a century, though the statement that grain from Egyptian tombs still maintains its power of growth has been disproved. The ability to continue dormant life clearly seems to depend to a large extent on the presence of a dry enclosing membrane, since under these conditions the entrance of gases is impossible and the chemical processes within are at a minimum. Thus it is apparent that certain organisms may survive unfavorable conditions for a long period, and we have no reason for believing that the limits of endurance of other forms do not greatly exceed that of the few which have thus far been studied.

---

[13] Verworn M., "Allgemeine Physiologie," 6th ed., 1915. English translation of 2d edition by F. S. Lee, 1899.

On the other hand, the exigencies to which living matter would be exposed when started on its interstellar journey are not inconsequential. Meteors in their fall through the earth's atmosphere become incandescent and, if they are the vehicle of transfer, it would only be conceivable for life to survive far below the surface where the temperature is lower. To avoid this and other difficulties it has been suggested by Arrhenius that the radiation pressure of light is sufficient to overcome the attraction of gravitation for particles of the extraordinary minuteness of some of the lowest forms of life, and that isolated germs might make the journey to the earth. But on the assumption that such an individual organism were forced out into space by the mechanical pressure of the light waves from the sun of the nearest solar system, it would require many thousand years to reach the earth. Only on the view that cells are potentially immortal and can remain in a dormant condition nearly indefinitely can we believe that life has reached the earth from other planets. Arrhenius maintains that this is possible owing to the exceedingly low temperature and absence of water-vapor which must prevail in cosmic space; and Loeb states that there is no reason why spores should lose appreciably more of their germinating power in ten thousand years than in six months.[14]

Without further discussion it is apparent that the theory is one which cannot be proved or disproved. At first thought, and as first outlined by Richter, it commanded little serious attention; but with its strictly scientific formulation by later physicists and biologists, and especially in view of our increasing appreciation of the potentialities of life in the latent state, we are justified perhaps in seriously questioning, with Helmholtz, "whether after all life has ever arisen, whether it may not be even as old as matter, and whether its germs, passing from one world to another, may not have developed where they found favorable soil." But the majority of biologists undoubtedly would agree with Schäfer that, "knowing what we know, and believing what we believe, as to the part played by evolution in the development of terrestrial matter, we are, without denying the possibility of the existence of life in other parts of the universe, justified in regarding these cosmic theories as inherently improbable—at least in comparison with the solution of the problem which the evolutionary hypothesis offers."[15]

[14] Arrhenius, S., "Worlds in the Making." English translation by H. Borns, 1908.

Loeb, J., "The Organism as a Whole from a Physicochemical Viewpoint," 1916.

Woodruff, L. L., "Eleven Thousand Generations of Paramecium." Quar. Rev. Biol., vol. 1, 1926.

[15] Schäfer, E. A., "Life: Its Nature, Origin and Maintenance." Presidential address, Brit. Assoc. Adv. Sci. *Science,* new ser., vol. 36, 1912, pp. 289-312.

With this in mind we may briefly survey some of the modern scientific conjectures which attempt to formulate the phenomena attendant upon the evolutionary origin of matter in the living state from the inorganic upon the earth.

Pflüger's theory. Assuming that the surface of the earth was once incandescent, Pflüger has offered a suggestive theory the crucial points of which turn on the chemical characteristics of the proteins. He emphasizes that there is a fundamental difference in the nitrogenous radicals of what he terms "dead" proteins, as egg albumin, and "living" proteins taking an active part in the economy of protoplasm, since the nitrogenous decomposition products of the latter either contain the cyanogen radical or can be artificially produced from compounds of cyanogen by atomic rearrangement. This suggests to Pflüger the probability that the cyanogen radical is an integral part of the molecular complex of living proteins and since in the formation of cyanogen a large amount of heat is absorbed, it follows that this radical possesses a large amount of internal energy and thus with it there is "introduced into the living matter energetic internal motion."

Pflüger's idea that the protein molecules of living protoplasm owe their diagnostic characteristics, in particular their lability, to cyanogen is supported, he believes, by certain analogies, which we need not consider, between cyanogen compounds and "living" proteins. Indeed, he says, the "similarity is so great that I might term cyanic acid a half living molecule." "When we think of the beginning of organic life, we must not think primarily of carbonic acid and ammonia; for they are the end of life, not the beginning." "The beginning lies rather in cyanogen." Pointing out that cyanogen and its compounds arise only in an incandescent heat, he holds that "life is derived from fire, and its fundamental conditions were laid down at a time when the earth was still an incandescent ball." Thus living material owes its genesis to cyanogen compounds which, on account of their tendency to decomposition, entered into relations with carbon compounds arising at similar temperatures. When the temperature conditions of the earth's surface permitted the precipitation of water, this with the salts and gases in solution joined the growing cyanogen-carbon complex and gave rise to the highly labile protein molecules so characteristic of protoplasm. Thus, according to Pflüger's hypothesis, arose a relatively simple, homogeneous material from which has been evolved the highly differentiated protoplasmic masses or cells of organic life today.[16]

Moore's theory. Moore essays to picture with rather bold strokes the origin of life from the inorganic elements of the cooling earth, by a continuation of the slow process of complexification which he sees inherent in matter. "This note," he says, "cannot be too strongly sounded that as matter is allowed capacity for assuming complex forms those complex forms appear. As soon as oxides can be there, oxides appear; when temperature admits of carbonates, then carbonates are forthwith formed. . . . Next in order of development prior to life inorganic colloids begin to appear in solution, or suspension, in the waters of the cooling globe, alumina and silica deposited in colloidal form are seen in many sedimentary rocks. Single molecules existing in solution, and capable of forming colloids, with alterations in temperature, and in chemical reaction of the environment, begin to form complexes, or solution aggregates, in which the unit of chemical structure passes from the atom to the molecule."

Accompanying these structural changes, the energy types and phases inhabiting the unit of structure also vary. The rates of vibration or of phasic activity in the colloidal aggregates become slower than in the simpler molecules of the crystalloids. The characteristics of colloids, slowness of reaction, metastable equilibrium, delicacy of union, and increased reactivity of specific type, become present in the forms of matter now capable of existing in equilibrium with the environment. As the complexity of structure increases, the nature of the equilibrium in the colloidal aggregates approaches more and more towards that labile, easily destroyed, but also more readily constructive condition which is characteristic of life.

---

[16] Cf. Verworn, *op. cit.*

Pflüger, E., "Ueber die physiologische Verbrennung in den lebendigen Organismen." Arch. f. d. ges. Physiol., vol. 10, 1875.

Moore then states in a general way as a "law universal in its application to all matter, although varying in intensity in different types of matter, and holding throughout all space as generally as the law of gravitation—a law which might be called the Law of Complexity—that matter so far as its energy environment will permit tends to assume more and more complex forms in labile equilibrium. Atoms, molecules, colloids and living organisms arise as a result of the operations of this law, and in the higher regions of complexity it induces organic evolution and all the many thousands of living forms." In this manner he conceives that the hiatus between non-living and living things can be bridged over, and that life arose as an orderly development, which comes to every earth in the universe in the maturity of creation when the conditions arrive within the suitable limits.[17]

Allen's theory. We may now consider certain theories which conform with the primal earth conditions as postulated by the planetesimal theory of its origin. Allen, for example, maintains that it is simplest to believe that the circumstances which support life would also favor its origin and that if life formerly existed actively outside the range of the freezing and boiling points of water, it must have been quite different from that which now exists. Life then arose at the period when the physical conditions of the earth came to be nearly what they are at present. At such a time, as now, discharges of lightning passing through the damp air produced ammonia and oxides of nitrogen, which were carried down by rain into the streams and pools. If this process went on unmodified, the result would be a large accumulation of nitrogen compounds in the terrestrial waters, which would also contain carbon dioxide probably in larger amounts than the waters of the present day, because since that time much carbon dioxide has been withdrawn from the air and water and locked up in organic matter. In the same waters the usual metallic elements, in the form of chlorides, sulphates, phosphates, etc., would also be present.

---

[17] Moore, B., "The Origin and Nature of Life," 1912.

Thus there must have been brought together an abundance of such raw materials as are required for the production of living matter, and, provisionally, Allen imagines some such reactions as the following to have occurred: solar energy, acting on the water or damp earth containing the raw materials just mentioned, caused dissociation and rearrangement of the atoms, the nitrogen abstracting oxygen from its compounds with carbon, hydrogen, sulphur, and other elements and delivering it to the atmosphere. Not much energy would be absorbed by a transparent liquid; but such actions as the above would occur particularly in water containing compounds of iron in solution or suspension since these compounds would absorb the solar energy. In this way compounds of nitrogen, carbon, etc., accumulated in the water or damp earth; and further reactions, anabolic and catabolic, occurred among them by virtue of the lability of the nitrogen compounds. Life at this stage was of the humblest kind since there were no definite organisms, only diffuse substances trading in energy, and between this stage and the evolution of cellular organisms an immense period probably elapsed.

Allen questions whether the earliest organisms were able to utilize the energy of sunshine or whether their whole energy was derived from the nitrogen compounds produced in the atmosphere by lightning, but in any case he thinks the faculty of appropriating the energy of sunshine must have developed at an early period, if not at the very beginning. In the functions of life, constructive process precedes destructive, and it therefore seems reasonable to suppose that the earliest forms of life were concerned more in accumulating than in dispersing energy, and that the energy-dispersing organisms, like bacteria and fungi, have had a comparatively late origin.

Allen's view of the origin of life "implies that the first attempts at life are still continuing, and that if by chance all life were wiped out, another cycle would begin." Such he believes to be the case, and to the question, "Why do we not find evidence of these processes in the form of primitive vital substances in water or elsewhere?" he answers that as soon as any such substances begin to be formed, they are seized and assimilated by the already developed organisms.[18]

Troland's enzyme theory. With the increasing realization of the importance of enzymes in the economy of organisms it is not strange that in these chemical bodies has been sought the key to life's origin, and accordingly we find Troland stating that life is something which has been built up about the enzyme. This author assumes that, at some moment in earth history, a small amount of a certain autocatalytic enzyme suddenly appeared at a definite point within the yet warm ocean waters which contained in solution various substances reacting very slowly to produce an oily liquid immiscible with water. If, when this occurred, the enzyme became related to the reaction in such a way as to greatly increase its rate by reducing the chemical friction involved, Troland believes it is obvious that the enzyme would become enveloped in the oily material resulting from the reaction, and the little oil drop would increase until it was split into smaller globules by water currents, provided the original substances which combined were soluble in oil as well as in water. Thus arose, according to his theory, the first and simplest life-substance, possessing the power of indefinitely continued growth, by virtue of the postulated autocatalytic character of the initial enzyme. Troland is convinced that this theory of the origin of life satisfies most of the objections which have been advanced against ordinary chemical hypotheses, since the characteristic catalytic power of the enzyme accounts for the elevation of the rate of synthetic action from practically zero to one making possible rapid growth of the protoplasmic mass. The same catalytic property explains the localization of the reaction in a definite region, for catalysis can occur only where the catalyzer itself is present. "The theory also provides a basis for the permanent growth of the primitive organism—if such we dare to call it—as well as for its reproduction, without, in general, the loss of its specific individuality." Troland suggests that the most fundamental objection which can be raised against his ideas is the fortuitous formation of the original enzyme; but he insists that since only a single molecule of the enzyme was required, and since multitudinous chemical reactions undoubtedly took place in the primordial ocean, this objection of improbability is almost absurd.[19]

---

[18] Allen, F. J., *op. cit.*

Osborn's theories. A still more recent consideration of the origin of life is that published by Osborn a few years ago. Starting with the postulate that "the primal earth, air, and water contained all the chemical elements and three of the most simple but important chemical compounds, namely, water, nitrates, and carbon dioxide, which are known to be essential to the prechlorophyllic and chlorophyllic stages of the life process," Osborn suggests that an initial step in the origin of life was the coördinating or bringing together of these elements, which, so far as we know, had never been in combined action before. He states that the thermal conditions of present-day living matter point to the probability that this coördinating of the "life elements" was initiated when portions at least of the earth's surface and waters had temperatures of between 6° and 89° C. and before the atmospheric vapors admitted a regular supply of sunlight. The earliest function of living matter appears to have been to capture and transform the electric energy of the chemical elements characteristic of protoplasm, and this power probably developed only in the presence of heat energy derived from the earth or from the sun. Frankly admitting, however, that both the time and place of the origin of life is a matter of pure speculation, in which we have as yet no observations or uniformitarian reasoning to guide us, Osborn advances five hypotheses in regard to it as follows:

---

[19] Troland, L. T., "The Chemical Origin and Regulation of Life." *The Monist,* vol. 24, 1914, pp. 92-133.

An early step in the organization of living matter was the assemblage of several of the chemical elements essential to life. Of these the four most important elements were obtained from their previous combination in water, from the nitrogen compounds of volcanic emanations or from the atmosphere, consisting largely of nitrogen, and from atmospheric carbon dioxide. The remaining elements came from the earth.

Whether or no there was a sudden or a more or less serial grouping of these elements, one by one, Osborn is led to a second hypothesis that "they were gradually bound by a new form of mutual attraction, whereby the actions and reactions of a group of life elements established a new form of unity in the cosmos, an organic unity or *organism* quite distinct from the larger and smaller aggregations of inorganic matter previously held or brought together by the forces of gravity."

This leads to the hypothesis that since all living cells are colloidal the grouping of the "life elements" took place in a state of colloidal suspension, for it is in this state that the life elements best display their incessant action, reaction, and interaction.

With this assemblage, mutual attraction, and colloidal condition, a fourth hypothesis is that there arose the rudiments of competition and selection. "Was there any stage in this grouping, assemblage, and organization of life forms, however remote or rudimentary, when the law of natural selection did not operate between different unit aggregations of matter? Probably not, because each of the chemical life elements possesses its peculiar properties which in living compounds best serve certain functions. This coöperation was also an application of energy new to the cosmos." In other words, every "life element" has its single and multiple services to render to the organism.

And as a fifth hypothesis relating to the origin of organisms, Osborn advances the idea that the evolution and specialization of various enzymes has proceeded step by step with the evolution of plant and animal functions, "since in the evolution from the single-celled to the many-celled forms of life and the multiplication of these cells into hundreds of millions, into billions, and into trillions, as in the larger plants and animals, biochemical coördination and correlation become increasingly essential."[20]

Conclusion. Such are the principal attempts of modern biologists to formulate in some concrete way the evolution of matter in the living state from the elements of the earth. Their consideration is valuable in that it indicates the uniformitarian trend which, at the present day, biological thought follows in this field, and also the diversity of results arrived at by the scientific imagination when it is largely untrammeled by facts. One, however, cannot but admire the scientific caution of Huxley when he said:

---

[20] Osborn, H. F., "The Origin and Evolution of Life," New York, 1917.

"Looking back through the prodigious vista of the past, I find no record of the commencement of life, and therefore I am devoid of any means of forming a definite conclusion as to the conditions of its appearance. Belief, in the scientific sense of the word, is a serious matter, and needs strong foundations. To say, therefore, in the admitted absence of evidence, that I have any belief as to the mode in which existing forms of life have originated, would be using words in a wrong sense. But expectation is permissible where belief is not; and if it were given to me to look beyond the abyss of geologically recorded time to the still more remote period when the earth was passing through physical and chemical conditions, which it can no more see again than a man can recall his infancy, I should expect to be a witness of the evolution of living protoplasm from not living matter. I should expect to see it appear under forms of great simplicity, endowed, like existing fungi, with the power of determining the formation of new protoplasm from such matters as ammonium carbonates, oxalates and tartrates, alkaline and earthy phosphates, and water, without the aid of light. That is the expectation to which analogical reasoning leads me; but I beg you once more to recollect that I have no right to call my opinion anything but an act of philosophical faith."[21]

Thus since biologists are at the present time absolutely unable, and probably will be for all time unable, to obtain empirical evidence on any of the crucial questions relating to the origin of life on the earth, their endeavors are and must be directed chiefly toward an intensive analysis of life manifestations as exhibited in the physical basis of individual organisms, in their bionomic relations, and in the kaleidoscopic panorama which geological history presents of their evolution.

---

[21] Huxley, T. H., "Biogenesis and Abiogenesis." Presidential address, Brit. Assoc. Adv. Sci., 1870. "Collected Essays," vol. 8.

In the closing words of Darwin's *Origin of Species:*

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. . . . There is grandeur in this view of life with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."

CHAPTER IV

THE PULSE OF LIFE

RICHARD SWANN LULL

STERLING PROFESSOR OF VERTEBRATE PALEONTOLOGY, YALE UNIVERSITY

THE stream of life flows so slowly that the imagination fails to grasp the immensity of time required for its passage, but like many another stream, it pulses as it flows. There are times of quickening, the expression points of evolution, and these are found to be coincident with geologic change. These coincidences are so frequent and so exact that the laws of chance may not be invoked to account for them. They stand to each other in the relation of cause and effect.

This does not imply the acceptance of any one philosophical factor of evolution, for whether the creature is directly modified by environmental change, or indirectly through induced habit, or whether nature merely sets a standard to which the organism must attain if it would survive, matters not; the fact remains that changing environmental conditions stimulate the sluggish evolutionary stream to quickened movement. Whenever it has been possible to connect cause and effect, the immediate influence is found to be generally one of climate, back of which lies, as the main cause, earth shrinkage and a consequent warping of the crust, with the elevation and spread of the lands and the formation of mountain ranges. In addition to this mundane cause, there are the complex rhythms in solar energy and the consequent variation in the amount of solar-derived heat. For example, the most generally accepted single cause of the last or Pleistocene glacial period is the great continental elevation which formed the Cascadian revolution, but, so far as our knowledge goes, that would not account for the successive advances and retreats of the ice mantle, with the attendant climatic variation, and some other factor such as the rhythms of solar energy must be invoked as of supplemental influence. Nevertheless, the ultimate source of profound and far-reaching crises in the evolution of the organic world may have been, geologically speaking, of a very simple character.

Through the collaboration of my colleagues, Professors Schuchert and Barrell, the appended chart, Figure 14, has been prepared to show the relation between the changing continental elevation and climate. To this I have added a curve representing the consequent acceleration and retardation of the evolutionary stream. The climatic records of pre-Paleozoic time are so vague and unreliable that it was not thought wise to include the vast Archeozoic and Proterozoic eras within the scheme. The time values of the several included eras are not proportionally indicated, too much space by far being given to the Cenozoic because of its biologic interest. As a matter of fact, its duration is more nearly comparable to that of Permian time.

The curves are necessarily generalized, for there was neither space nor necessity for greater detail. In the altitudinal curve, the upslope of the diastrophic peaks signifies rising diastrophism; the downslope, the period of erosion before the continents are low enough to have mantles of sediment spread upon them. A greater or lesser part of the peak and downslope represents, therefore, the unrecorded interval between eras or periods, as the case may be. The tangential lines drawn to the diastrophic peaks show the relation of a series of movements: a gradual rise culminating in the great revolutions. Were the Cenozoic compressed into its normal

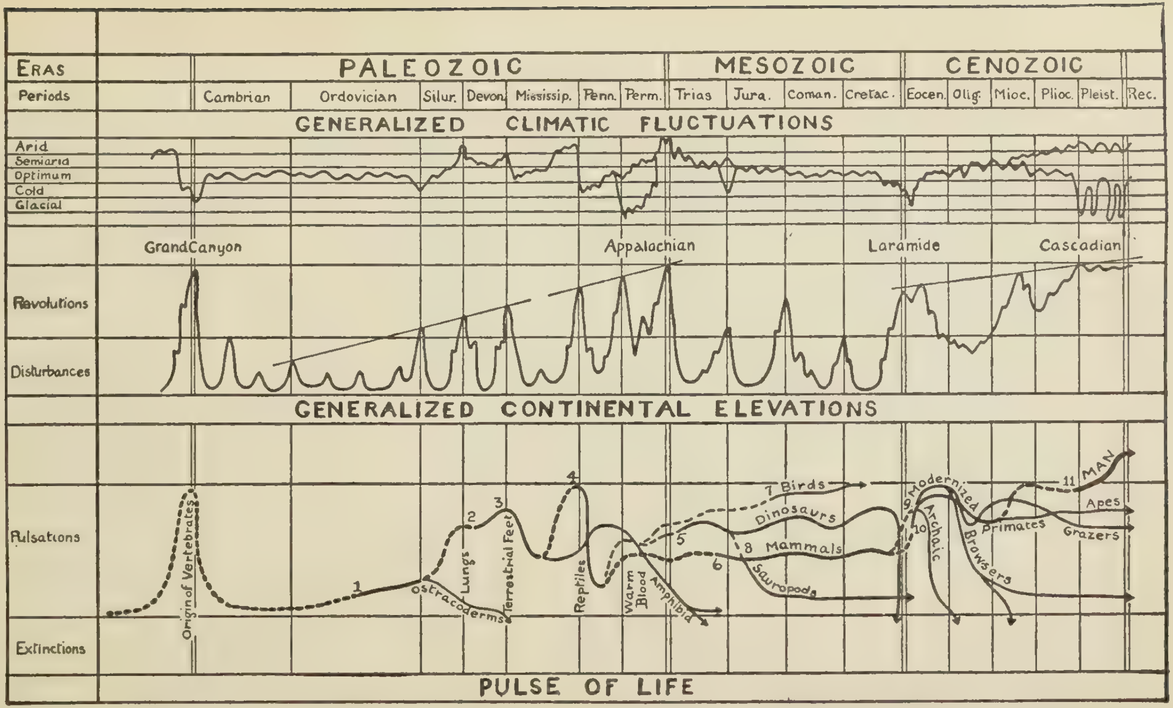


FIG. 14.—Diagram of the pulse of life. Climatic line: minor jogs merely indicate climatic oscillations; doubling of lines, climatic zones where aridity and cold are differentiated; single line, uniformity of conditions the world over. Continental elevation line: up-slopes mean rising diastrophism; down-slopes, periods of erosion before continents are low enough to have mantles of sediment spread upon them, i.e., the intervals. Tangential lines show gradual rise culminating in great revolutions. Whole Cenozoic has about the time valuation of the Permian; is all a period of revolution, and its compression to uniform scale would give the tangent to the peaks about the same slope as in the

relative length, the slope of the tangent drawn to its peaks would correspond more nearly to those of the Paleozoic.

In the climatic line, the minor undulations indicate in a very general way the climatic oscillations which must have existed but of which we have as yet no very exact data; the larger movements, on the other hand, are based upon observed fact. The optimum embraces a normal range of temperature and degree of moisture; a rising curve, increased aridity; its depression, a lowering of temperature. Where the line is single here is a supposed uniformity of conditions the world over; where it splits, aridity and cold are differentiated. It is highly probable that with more detailed knowledge the divergence of he moisture and temperature curves will be more extensive.

The life line is dotted where theory precedes the recorded act, solid when actual fossils attest the truth of the assumed volution. The numbers indicate the times of these first records as follows: 1, first vertebrates; 2, lung-fishes; 3, verterate footprints; 4, reptiles; 5, dinosaurs; 6, mammals; 7, irds; 8, amphibious dinosaurs; 9, archaic mammals; 10, modrnized mammals; 11, man. (See page 145.)

CRISES OF EVOLUTION

Origin of life. The first great crisis in the evolution of rganic beings was the origin of life: the marvelously subtle ombinations attained by certain very familiar inorganic eleents, increasing their molecular complexity until a substance as produced endowed with the attributes of life. Of this omentous event we have no record, nor does the geologic use come either within the scope of our knowledge or concture, for the time was too remote and the first living subance too delicate to leave any decipherable record upon the ocks. All we can say of it is that in the fullness of time, when e earth had, in the course of its physical evolution, become dapted as the abode of life, living substance came into being.

Establishment of the lime-secreting habit. The first *recorded* crisis, that of the assumption of the lime-secreting habit—perfected by animals in the Upper Cambrian, by plants, marine algæ, much earlier—has again no *accepted* geologic cause. The importance of this crisis is doubtless not as great as that of many unrecorded ones which had gone before, its significance lying mainly in the fact that the development of hard parts enabled the organisms which bore them to write imperishable records of their existence upon the rocks. Previous to this, the indications of life are indirect, such as the accumulation of graphite, which is never produced in nature except as the result of organic activity; or the records are in the nature of the rare fossils of algæ, of Protozoa (Radiolaria), and of the burrows of annelid worms. It may be assumed that the presence of Protozoa, on the one hand, and of Annelida, on the other, in late Proterozoic sediments implies the existence of all the intermediate phyla of invertebrates—sponges, cœlenterates, flat and round worms—and the probabilities are that all the other invertebrate groups except the Arthropoda were also present.

The culmination of this crisis, like several which are yet to be discussed, did not come until long after its inception, for while certain creatures like the Archæocyathinæ (probable corals) and brachiopods show limy skeletons in the early Cambrian, others were as yet chitinous, and it is not until the Middle Ordovician that the process is entirely complete.

The definite fossil record thus established shows us that the evolution of great invertebrate groups occurred largely before the close of the Proterozoic, hence we may not speak confidently of cause and effect. Vertebrate evolution, on the other hand, lies within the period of recorded evolutionary history, and while there is little direct evidence regarding the origin of this important phylum, the evolutionary crises through which it passed are entirely within the scope of our observation. That the invertebrates also have advanced since the Proterozoic is certainly true, but their evolution is largely one of detail and does not represent the establishment of any new principle or type, that is, if we except the insects. With the vertebrates, however, this is not true, for some of the most momentous advances in the evolution of higher forms lie within the range of their fossil record.

Origin of vertebrates. The distinction between the vertebrates and invertebrates is largely dynamic, for the former are principally motor types, the latter largely quiescent, sluggish forms, often actually sedentary, that is, attached to the substratum or other object. A review of invertebrates, especially the aquatic forms, will serve to emphasize this point. The sponges are entirely sedentary, while the cœlenterates are either fixed forms like the corals or capable of very slight creeping locomotion like the sea-anemones; or are feeble swimmers like the jelly-fishes, subject to the whim of tidal and other marine currents, or to the turmoil of a wind-swept sea. Of he worms, using the term in its old collective sense, some gain are fixed, some crawling, some feeble swimmers, and the ame is true of echinoderms and many molluscs. The arthropods are perhaps the most venturesome of marine invertebrates except the cephalopod molluscs, but even to them do the ame three conditions of fixedness, crawling, or none too effective swimming apply. Such as are pelagic are, like the jelly-sh, so non-resistant as to be largely the victims of circumstance. Of all aquatic invertebrates, the cephalopods alone have eveloped locomotive powers of marked significance, but their comotion is strikingly different from that of a vertebrate in hat it is the perfection of a method of jet propulsion which ther invertebrates have also developed, although none have rried it so far. Briefly, the perfected cephalopod, such as e squid (see Fig. 15), has an elongated, spindle-shaped dy, at the hinder pointed end of which are two horizontal stabilizing fins that may be used for slow forward swimming by means of wave-like undulations. The body is enclosed in a muscular fold of the body-wall known as the mantle, but does not fill it, leaving a space beneath known as the mantle cavity. There is on the under side of the well-developed head, with its huge eyes and long tentacles, a tubular funnel (Fig. 15, *f*) whose larger end connects with the mantle cavity, the smaller one pointing forward beneath the head. Relaxation of the mantle permits the ingress of water into the cavity; closure of the muscular margin around the animal's neck, on the other hand, prohibits its egress except through the funnel. A forcible contraction of the entire mantle forces the water out in a sharp jet which impinges against the surrounding water and thus drives the creature backward at a very rapid rate. As compared with the easy undulatory movements of an aquatic vertebrate, however, this jet propulsion mode is highly costly of effort, and its adoption by mankind for steam-propelled craft was to meet peculiar conditions of short choppy seas and a disastrously "racing" screw propeller rather than because of any inherent virtue in the basic idea. Its rejection from ordinary usage is due largely to its extreme lack of economy.

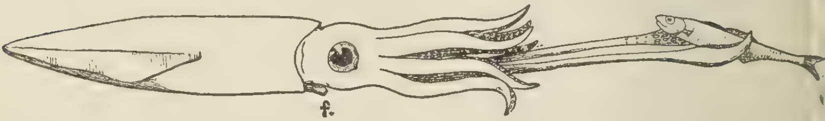


Fig. 15.—Squid, *Loligo* sp., capturing a fish: *f*, funnel. After Doflein, from Lull's "Organic Evolution," published by the Macmillan Company.

The cephalopods, being predaceous forms, must overtake their prey, and in turn must flee from devouring Cetacea for which they form a principal dietary staple, hence their urgent need of locomotion; but for the great host of invertebrate forms their static habitat places no premium upon locomotive

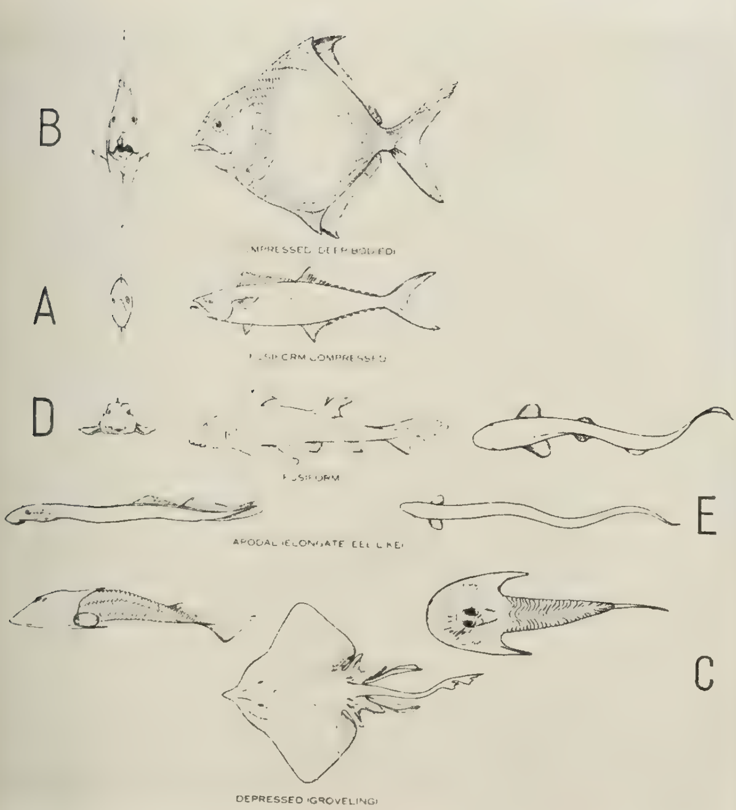


Fig. 16.—Fish forms. From "The Origin and Evolution of Life," by Henry Fairfield Osborn; copyright, 1917, by Charles Scribner's Sons.

powers, and the evolution of so marked an attribute as high speed must have some powerful incentive. The thesis has been advanced therefore that the main distinction between vertebrate—or more properly chordate—and invertebrate is largely a response to habitat, the invertebrate being the product of static waters, marine or sluggish terrestrial, where an effortless existence, carried hither and yon by wave and tide, would not remove it from the environment. The chordate, on the other hand, is the outcome of dynamic or flowing terrestrial waters which *enforced* swimming powers as the only means of resisting eviction from the realm. The distinction is not one of contour, for the fusiform shape of the speedy animal is the result of swift movement through a more or less resistant medium, whatever the motive power; but the segmental body muscles, the internal resistant axis, and the fin-like expansions to resist the thrust of the muscles, all are the direct outcome of the mode of locomotion, that by lateral undulation of a primitively elongated body. (See Fig. 16.) That this locomotive device *might* have been developed in static waters is not denied, for some marine worm-like organisms swim by a wriggling movement, though invariably in the dorso-ventral plane, but there is in the sea little incentive to enforce its rapid perfection, such as dynamic waters would produce. Hence the assumption that the vertebrates are the outcome of terrestrial waters. To illustrate the means whereby the evolution was initiated, Chamberlin[1] has discussed the peculiar habit of a stream-borne lamprey, *Petromyzon* (Fig. 16, E, left-hand eel), which adheres to the bottom by its suctorial mouth and allows its body to undulate in the pulsating current as a flag is whipped in the breeze or a rope of grass in the stream. Unless the stream be very shallow so as to cause distinct vertical displacements of the water, this undulation is always lateral or

---

[1] Chamberlin, T. C., "On the Habitat of the Early Vertebrates." *Jour. Geology*, vol. 8, 1900, pp. 400-412.

in the horizontal plane, as that is the direction of least resistance because of the inhibitive force of gravity. When the lamprey wishes to swim to maintain its position in the current, it simply reproduces in the active voice the motions imparted to it in the passive voice by the stream itself. More forcible action drives it ahead. Such motion, consisting as it does of a series of reversed curves, requires segmented muscles on either side, along which alternating waves of contraction may pass. An axial stiffening to resist the longitudinal compression of such muscles is also necessary. This is first a pliant cellular membrane rendered resistant by being tensely filled with liquid, next a supple rod of cartilage, and finally a bony axis, segmented for the sake of flexibility. The economic efficiency of this undulatory mode of progression as compared with the jet propulsive method of the cephalopod is evident to anyone who has observed the quick dart of a trout or the marvelously effortless progress of a school of porpoises at the bow of a ship.

As time went on, the assumption of the compact spindle shape of a swiftly swimming fish became, as we have argued, merely a speed response and not necessarily an exclusively stream-borne attribute. Depressed grovelling forms (see Fig. 16, C), or compressed highly specialized forms, are, however, either marine or static fresh-water in habitat, never stream dwellers.

It has been argued that as the most primitive existing chordates, *Amphioxus,* the tunicates, and the adelochordates (*Balanoglossus*), are marine, the ancestral chordates must have been also, but their distribution corroborates the hypothesis of fresh-water origin instead of denying it, for as Matthew[2] has shown, the most ancient members of a group are not to be found at the old center of evolution, but rather

---

[2] Matthew, W. D., "Climate and Evolution." *Ann. New York Acad. Sci.*, vol. 24, 1915, p. 180.

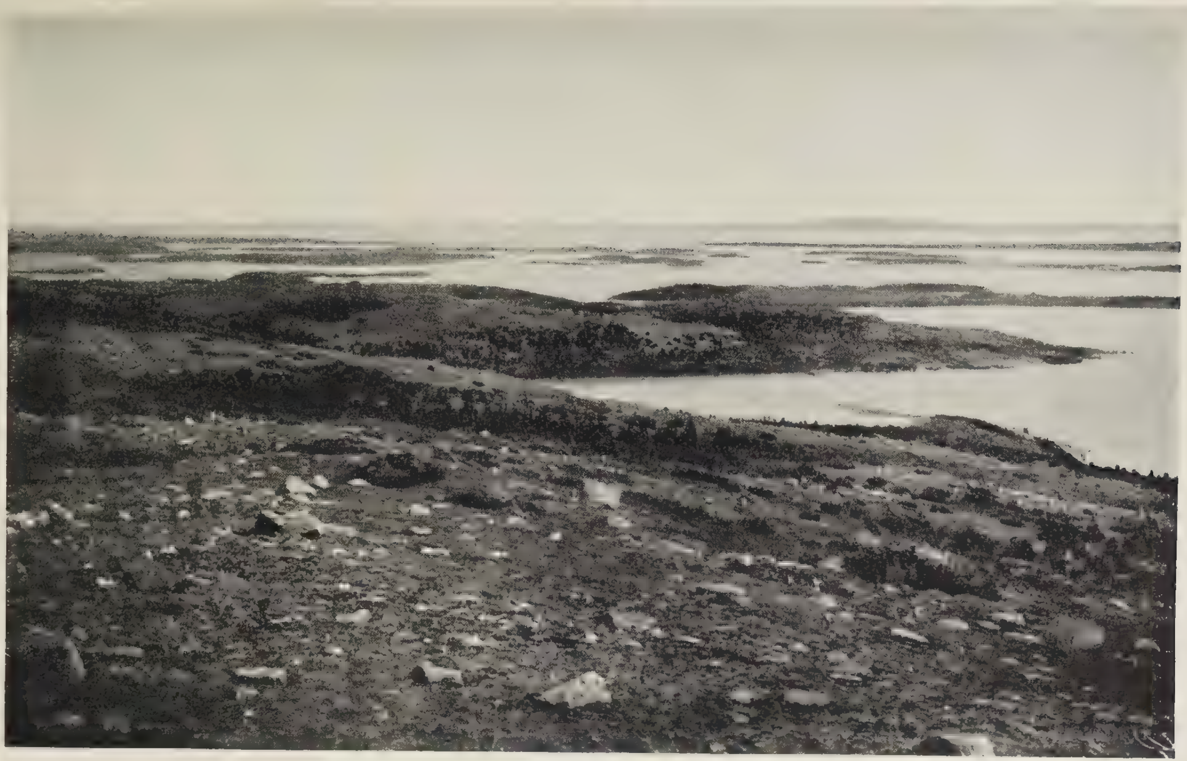


FIG. 17.—Laurentian peneplain as seen from the south end of Lake Michikamau, Labrador. From "Problems of American Geology," 1915, published by Yale University Press.

at the periphery of their migratory area. This is certainly true of these protochordates which, save for a few pelagic forms, are all found near the continental margins in the shallow seas. They are all degenerate and more or less sedentary, and hence could not maintain themselves in their fluviatile habitat and were swept into the sea—descendants of the less successful early tyros in the art of undulatory swimming.

But all of this requires as an impelling cause a change of habitat on the part of the invertebrate progenitors, either by a migration of the stock from static to dynamic waters, or by a change in the character of the waters themselves. The former view entails the necessity of some force to impel the migration, either the need for safety or food or the lack of salinity on the part of flowing waters, none of which seems adequate to compel so radical a change, and one along a line of so great resistance as the evolution of the invertebrate ancestor into the chordate implied. On the other hand, migration from the sea into sluggish terrestrial waters is more readily imagined, but affords no stimulus for chordate evolution. The picture of the Laurentian peneplain (see Fig. 17), with its low-lying lands and slow drainage, shown by glacial lakes, the result of recent choking of sluggish streams, suggests the solution, for while intermigration under such conditions would doubtless be relatively easy, it would never have stimulated chordate evolution. Geology records a great diastrophic movement toward the close of the Proterozoic, the so-called Grand Canyon revolution, partial evidence for which may be seen in the 8,000 to 12,000 feet of sediments, more or less conglomeratic, which were swept from mountains to the eastward and accumulated in the southern Appalachian region during the early part of Lower Cambrian time. This great upheaval changed the face of nature in many regions and quickened the static terrestrial waters to rapid and widespread movement over all the uplifted lands. Such invertebrate stocks as could neither cling to the bottom nor stem the quickening current were swept to the encircling sea and lost to the limnobiotic fauna; such as could, remained to people the fluviatile realm with creatures of a markedly higher sort.

The first recorded chordate, with the apparent exception of a recently discovered "fish plate" from the Cambrian of Vermont, comes from the Ordovician, but is an armored fish-like form, an ostracoderm, of grovelling habit and implied quiescent habitat (see Fig. 16, C). Such types, Patten[3] to the contrary, can hardly be considered as the first expression of chordate evolution, much less annectant forms between the vertebrates and the higher arthropods which they so closely resemble; rather were they a highly specialized offshoot of the primitive chordate stem, derived after the physical stimulus of quickened drainage had spent its force and times of quiescent waters had again appeared.

The evidence points, therefore, to the conclusion, that the place of chordate origin was the flowing land waters, to which may be added as the impelling cause a diastrophic movement which quickened the drainage, and, as the time of its inception, the interval following the Proterozoic era. This crisis is therefore the *direct* outcome of earth movement without the intervention of the climatic factor.

Emergence of terrestrial vertebrates. The waters, while a very necessary stimulus to early chordate evolution, afford too restricted an environment for the evolution of higher forms, and as a consequence all vertebrates whose ancestry can be traced back through an unending line of water inhabitants since the beginnings of life on earth are but fishes, and no matter to what degree they may have been specialized, they could not have risen nor can they ever rise to a higher plane. The emergence from the limiting waters to the limitless air was absolutely essential to further development and constituted one of the greatest crises in organic evolution.

To know the route of such migration is of the utmost importance if we would find a cause. In search of this, the mind turns at once to the land-encircling strand or tidal zone, stretching as it does over the many thousands of miles of the coast, the omnipresent frontier between land and sea. Here the conditions are varied, here there is food and light, and here the stimulus to double-breathing is enforced by the twice daily baring of the zone and its consequent transition from aquatic to terrestrial condition and back again with monotonous regularity. But in spite of its convenience, few indeed have been the stragglers of the vast army of aquatic life which have ever essayed its passage—land crabs and other crustaceans, certain molluscs, a few of the higher fishes such as the mud-skippers *Periophthalmus* and *Boleophthalmus,* all of which are impelled to a temporary or permanent migration shoreward by the need of food. And while they have developed accessory respiratory devices, the latter are merely spongy or other extensions or modifications of the water-breathing gills, and in no instance is there developed anything comparable in structure or ultimate efficiency to the terrestrial vertebrate's lung. Such structures as the latter have been developed only in fresh waters, all fishes which show it or its homologue, the swim-bladder, being either fresh-water or the descendants of fresh-water forms. The sharks forsook their ancestral waters before or when the need of such a structure was felt and have never developed it; on the other hand, all other fishes except the cyclostomes either have it or have lost it through specialization. In the modern fish, the swim-bladder has an hydrostatic function in that it serves to alter the specific gravity of the creature and thus enables it to maintain any given level in the water without further effort. As such, it is analogous to the water ballast tanks in a submersible ship, although the mechanism whereby the effect is produced naturally varies.

---

[3] Patten, W., "The Evolution of the Vertebrates and Their Kin," 1912.

The lungs of higher vertebrates are therefore identical with the swim-bladder of the fish and have retained and vastly improved the primal function of air breathing. This function is inconceivable as a prime requisite to marine life, and could only have arisen in terrestrial waters beyond the limits of the tidal zone,[4] where, due to increasing aridity of climate, the waters became reduced to stagnant pools which had neither sufficient flowage nor wave action to renew the supply of respirable air exhausted by the contained life. Such conditions prevail today in Australia, where the recurrent droughts cause the rivers to dwindle until only isolated pools are left. Within certain of these rivers, the Mary, Burnett, and Dawson, dwells an ancient relic form, the lung-fish or dipnoan *Neoceratodus,* which in times of habitat stagnation rises to the surface, gulps air (Fig. 18) into its lung, a highly vascular outgrowth or diverticulum of the alimentary canal, and thus aërates the contained blood. Other dipnoans also exist, as the African lung-fish, *Protopterus,* of the Nile, which, during times of drought, forms for itself a cocoon-like case of slime-hardened

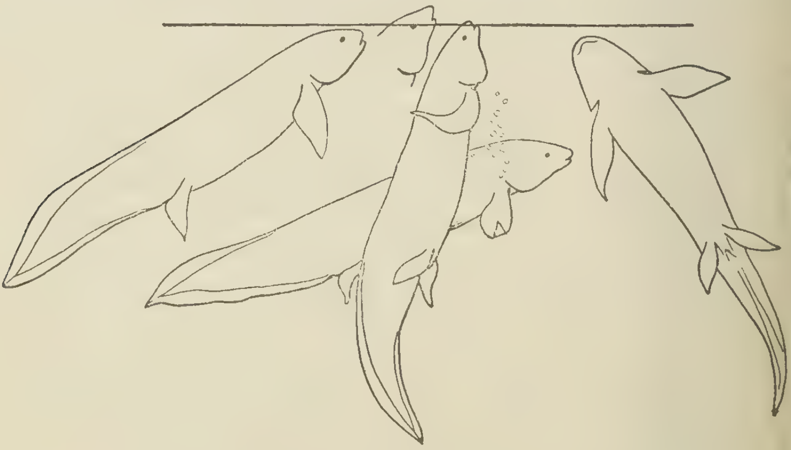


FIG. 18.—Lung-fish, *Neoceratodus*, breathing. After Dean.

---

[4] See Barrell, J., "Influence of Silurian-Devonian Climates on the Rise of Air-breathing Vertebrates." *Bull. Geol. Soc. America,* vol. 27, 1916, pp. 387-436.

mud in the river bottom and æstivates therein; and the South American lung-fish, *Lepidosiren,* of the Amazon River and its affluents, which lives near the margin of the water, using its lung almost with the regularity of a mammal, and also forming a burrow for its habitation during the dry season. Of these dipnoans the latter two belong to a group of which we have no fossil record; *Neoceratodus,* on the other hand, is a relic of what was formerly a large and widespread group. Yet another order of fishes in which the air-bladder has a respiratory value is the Crossopterygii, or fringe-finned ganoids, again an important and numerous group in the geologic past but now represented by but two genera, *Polypterus* (Fig. 19) and *Erpetoichthys,* both tropical African in distribution. While these living genera have not so effective a respiratory device as the dipnoans, nevertheless they present fewer anatomical difficulties to stand in the way of relationship with the amphibia. Without rehearsing the technical arguments, it may suffice to say that the generally accepted view is that the terrestrial vertebrates were derived either from ancient crossopterygians or from a group ancestral to both them and dipnoans.

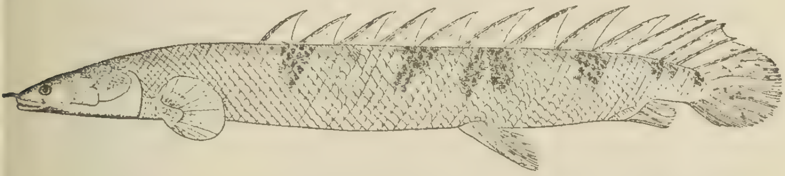


FIG. 19.—African fringe-finned ganoid, *Polypterus delhezi.* After Jordan, from Lull's "Organic Evolution," published by the Macmillan Company.

The geologic cause which lies back of the emergence is apparent. Diastrophic movement during the Silurian period (see Fig. 14) initiated a widespread aridity which culminated in the latter part of the period, continued with varying intensity into and through Devonian time, and rose again to greater severity in the latter part of that period. This meant, as in Australia today, the reduction of rivers and other bodies of fresh water and the entailed concentration of their fauna, which is borne out by the mode of occurrence of the Lower Devonian (Old Red Sandstone) fishes—innumerable specimens in very restricted areas. Add to this the diminution of aëration of these waters and it will be seen that a high premium would be placed upon powers of air breathing or of æstivation. Still further desiccation would necessitate some sort of activity during the increasingly long droughts, for the periods of torpor would otherwise bear too great a ratio to the creature's life span. Thus a premium would be placed upon ability to crawl ashore and maintain an active life, while the less fit would sleep the sleep that knows no waking, to their racial extinction.

Aridity, therefore, would place a premium, first upon lung breathing, the first recorded lung-breathing fish appearing in the Lower Devonian, although they must have existed in the Silurian; and later upon emergence, the entire process up to the perfection of the terrestrial limb covering more than the whole Devonian period, as the earliest known footprint of a terrestrial vertebrate is found in Upper Devonian rocks.

Evolution of the terrestrial foot. The question of the evolution of the pentadactyl hand and foot, which is the vertebrate standard, from the ancestral fish fin is not fully solved, but much light is thrown upon it by the above-mentioned footprint, known to science as *Thinopus antiquus* and preserved in the Peabody Museum at Yale. The slab of sandstone bears a single track (Pl. III), that of a right foot having two well-developed digits with distinct phalangeal impressions. On the outer side of the second digit is apparently a budding third, while lower down on the side of the foot may be seen the rudiment of a fourth. Rabl[5] has shown that the developing foot

---

[5] Rabl, C., "Gedanken und Studien über den Ursprung der Extremitäten." *Zeits. für wiss. Zoologie,* vol. 70, 1901, pp. 474-558.

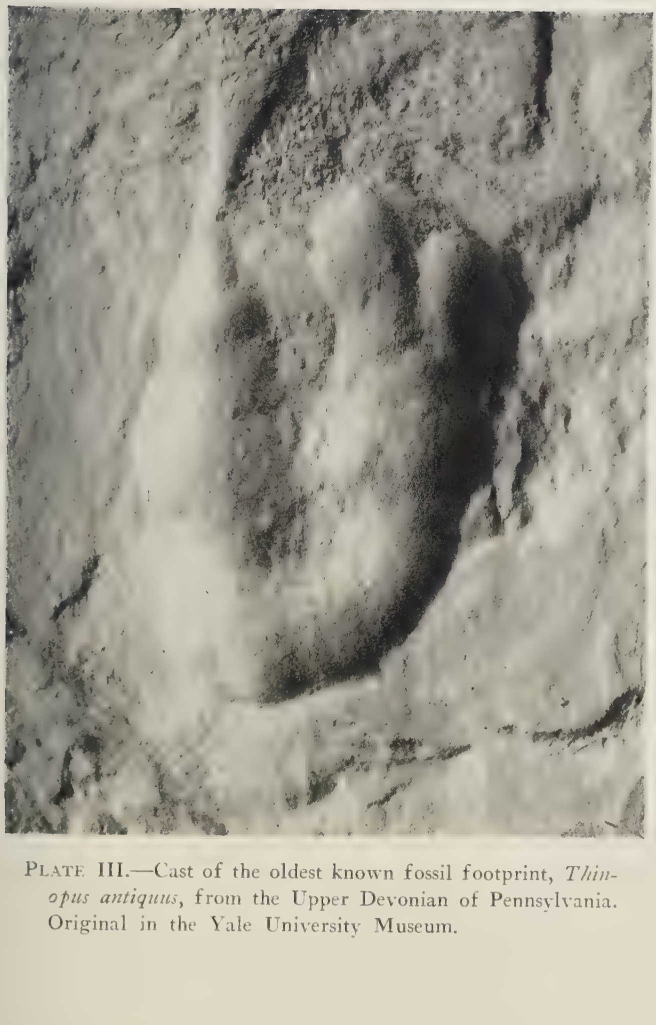


PLATE III.—Cast of the oldest known fossil footprint, *Thinopus antiquus*, from the Upper Devonian of Pennsylvania. Original in the Yale University Museum.

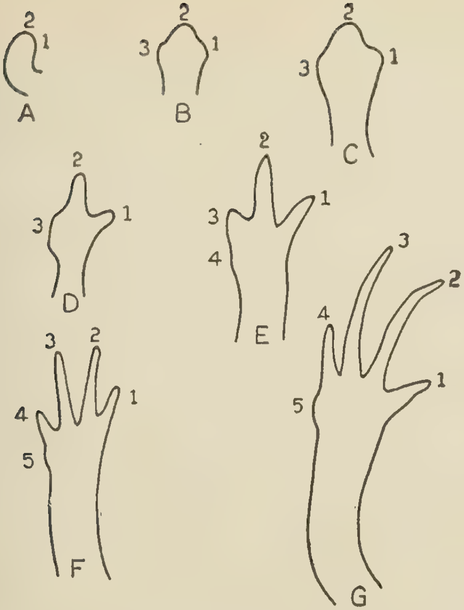


FIG. 20.—Development of the hind foot of a salamander, *Triton tæniatus.* After Strasser, from Lull's "Organic Evolution," published by the Macmillan Company.

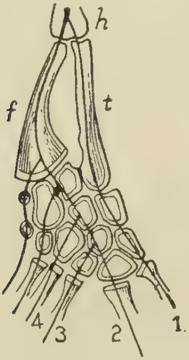


FIG. 21.—Foot of a reptile, *Ranodon sibericus: f,* fibula; *h,* femur; *t,* tibia; I, II, III, IV., digits 1-5. After Wiedersheim, from Lull's "Organic Evolution," published by the Macmillan Company.

of the embryonic amphibian, *Triton* (Fig. 20), passes through a series of stages of which one corresponds precisely to the degree of development of the Devonian track, which, from its size, is probably that of an adult although yet in the adolescence of its race. Comparative anatomy corroborates this belief and completes the tale of evidence (Fig. 21), in that the principal axes of the foot, as shown by the distribution of nerves and blood-vessels, lie in the first and second digits, the lesser axes of digits III, IV, and V arising as lateral branches from that of digit II.

With the opening of Mississippian time came increased moisture, and in the succeeding widely extended swampy forests of the coal period amphibia throve mightily and developed into the many sorts of so-called Stegocephalia or armored forms. That they still returned to their ancestral waters to bring forth their young, and that the latter bore gills upon the neck for aquatic respiration is evidenced by the actual traces of such structures in many fossil forms.

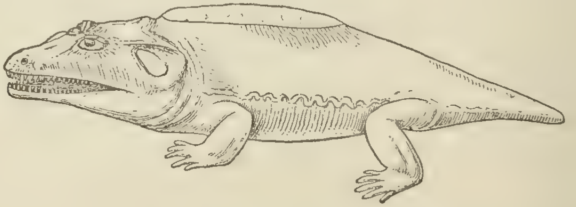


Fig. 22.—Restoration of the Permian stegocephalian, *Cacops aspidephorus*. After Williston, from the Pirsson-Schuchert "Text-book of Geology," published by John Wiley & Sons, Inc.

Origin of reptiles. During the latter half of the Mississippian, however, came a diastrophic movement with a wave of aridity, making the return to the natal waters increasingly difficult until many forms were forced to abandon it forever, and the reptiles came into being. There are today well-recognized criteria whereby a reptile may be distinguished natomically from an amphibian, but with certain forms, such s *Cacops* (Fig. 22) from the Permian red beds of Texas, e distinction is by no means so clear, for such as this were ansitional, *Cacops* being yet on the amphibian side of the ontier.

The change of habit induced by this aridity meant a radical ange in the character of the vertebrate egg, with the develop- ent of certain membranes (Fig. 23) whereby the contained oung could respire air, unnecessary in the water-laid egg. hus the terrestrial egg, typified by that of bird or reptile, is rge, with an abundance of nutrient "yolk" for the developing nbryo, and enclosed in a protective though porous shell. wo membranes are developed, the first of which, the amnion, merely protective, in that the cavity between its two layers ntains a fluid which serves to absorb mechanical shocks and guard the embryo against too rapid temperature changes. he other membrane is known as the allantois (see Fig. 23). his, when fully developed, lines the inside of the shell and abundantly supplied with blood-vessels, veins, arteries, and pillaries, which connect with the embryonic circulation. his is the respiratory device, for the blood coursing through e allantoic capillaries is thus in close osmotic relationship ith the air which penetrates the porous shell, and thus the ood is purged of its carbon dioxide gas and other volatile purities and receives its life-sustaining supply of oxygen. ch an egg must be laid on land or retained within the mother til it hatches, for the contained young would drown if the g were submerged, as surely as would the adult.

But the development of these membranes has a still deeper gnificance, because the allantois through an added function comes the intermediary between the unborn young and its ammalian mother, and hence its development, due to that r-off climatic change, has rendered possible the higher lacental) mammal with all which that implies to humanity.

Origin of warm blood. Toward the close of the Pennsylvanian commenced that series of earth movements which was to culminate in the Appalachian revolution and the passing of the Paleozoic, and as attendant phenomena came increasing aridity and, in Permian time, glaciation, which, in the southern hemisphere, exceeded in intensity and extent the so-called Glacial Period of the Pleistocene.

Aridity has its influence upon terrestrial types, at any rate upon the more progressive of them, in that it places a premium upon traveling powers, especially upon speed, for not only are food and water scarce and far between, but the strife between the pursuer and pursued becomes intensified—neither can afford to be outdistanced by the other. This means increased metabolism, which in turn generally implies not only greater motive powers but higher temperature. With increasing cold a premium would be placed upon such creatures as could maintain their activity beyond the limits of the shortening summers, and this could only be accomplished by the development of some mechanism whereby a relatively constant temperature could be maintained within the animal regardless of external conditions; in other words, warm, as opposed to cold (really variably temperatured or poikilothermous) blood.

This crisis means much, for the cold-blooded reptile has its most decided limitations. On the other hand, the evolution of the bird and mammal, the latter particularly, was rendered possible by the concurrence of these two factors, aridity and cold. Thus while actual recorded mammals (Upper Triassic) and birds (Upper Jurassic) are younger in time, their inception could hardly have been later than the Permian. Not that warm blood was at once attained, for that we believe to have been a relatively slow process, just as was the emergence. Indeed, in the existing egg-laying monotreme mammals the blood still ranges in temperature through at least 30° F., so with them the mechanism is not yet perfected.

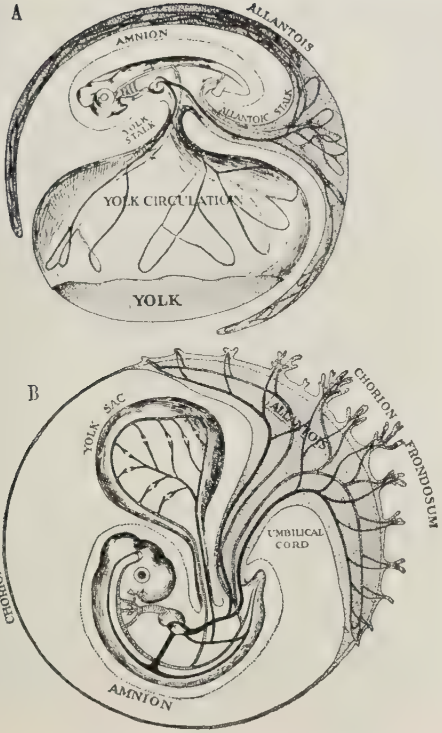


FIG. 23.—Diagram showing the relation of the extra-embryonal membranes. A, bird or reptile, with functional yolk-sac and respiratory allantois; B, mammal with functionless yolk-sac and with the allantois converted into an umbilical cord and placenta. From Wilder's "History of the Human Body," published by Henry Holt & Company.

Origin of mammals. These forms are clearly derived from reptilian stock known as the cynodonts or theriodonts (Fig. 4), in which the dentition has become differentiated as in the nammals into incisor, canine, and molar teeth. The reptiles liffer from the mammals in that the lower jaw is still a omplex of several bones, while in the mammal there is but ne on either side. Many cynodonts were long of limb and nust have traveled with the body well off the ground, which eems to have been a prerequisite to the development of warm lood. These cynodonts are widespread, but the evidence oints to certain of those of Africa as nearer the direct ancesors of the mammals; the record of the actual transition, owever, is as yet unrevealed.

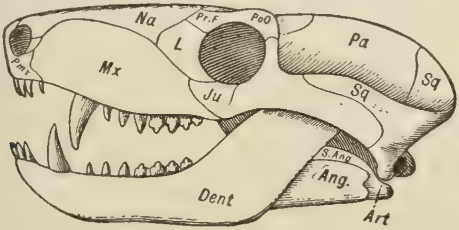


FIG. 24.—Skull of cynodont reptile, *Nythosaurus larvatus.* Note the mammal-like tooth differentiation, but complex reptilian jaw. After Broom, from the Pirsson-Schuchert "Text-book of Geology," published by John Wiley & Sons, Inc.

Origin of birds. Birds, on the other hand, came from nother, unrelated reptilian stock, that which also produced he dinosaurs. True flight, such as that which the birds deeloped, has been thrice evolved among the vertebrates and nce among the invertebrates. In the two other vertebrate roups, however, the flying mechanism involves not only the ore limbs, as in the bird, but also the hinder pair. With the irds, moreover, the hind limbs, as in dinosaurs, show a distinct adaptation of another sort, that for swift movement, hence the bird-like hind limbs of the dinosaur—or perhaps the converse of this statement would be more nearly true. Swift movement, which in this instance implies bipedality, evidently preceded flight, and its impression on the bird was so great that it has never been entirely relinquished despite the attainment of the higher faculty. Whether birds passed through an arboreal condition or whether they arose direct from cursorial types is unknown. It hardly seems probable, however, that more than one evolution occurred. We may conceive of a proavian as being at least partially arboreal and launching itself into the air from a convenient tree, sustained for a brief soaring glide on motionless fore limbs and tail, the scales of which had metamorphosed into buoyant feathers (see Plate IV, A). But the first recorded instance, *Archæornis* (Plate IV, B), of the Upper Jurassic, while still retaining the long lizard-like tail of its reptilian forebears, had already attained the power of *sustained* flight, though by no means so efficiently as the birds to come. There is again no fossil record of actual transitional forms.

Origin of dinosaurs. The same primal influence—aridity—which produced the bird may also have given rise to the dinosaur. Whether the latter came within the further influence of glacial cold and evolved a constant temperature of blood is not known; the total absence of any heat-retaining clothing in the dinosaurs, such as hair or feathers, is against such a supposition That their temperature rose decidedly during their periods of activity is, however, a reasonable assumption. Possibly the early dinosaur-like forms which dwelt within the influence of the Permian cold became the birds, while those beyond its influence remained dinosaurs and as such were destined to dominate the lands as no creatures before them had ever done

One is impressed by the influence of aridity in the evolution of bipedal dinosaurs in studying the Upper Triassic footprints

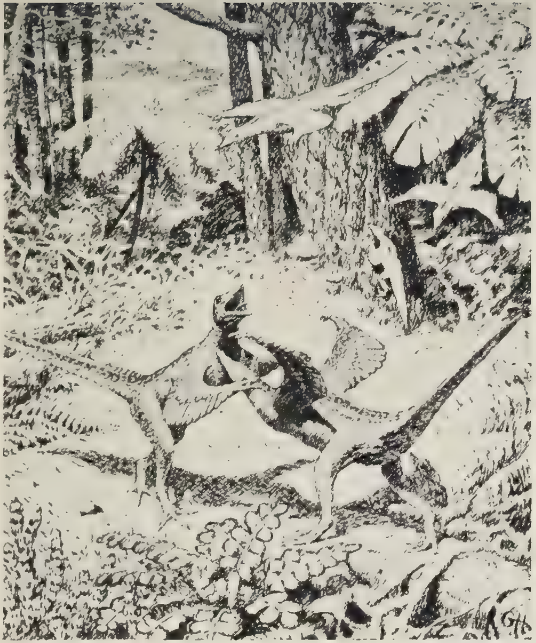


Fig. A

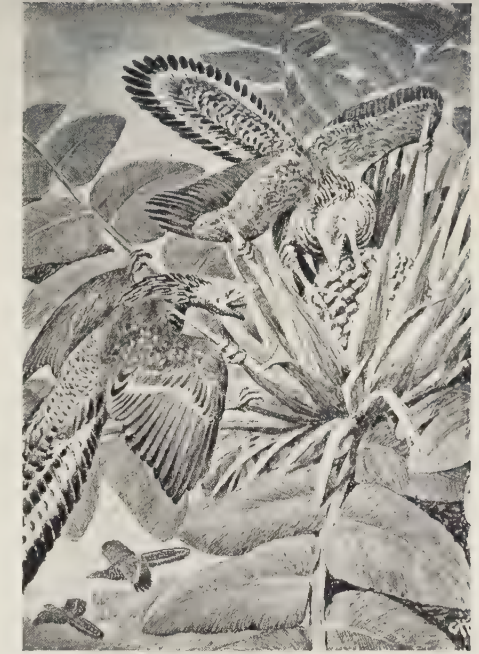


Fig. B

Plate IV.—Restoration of (A) the hypothetical proavian, and (B) the toothed bird *Archaeornis*. After Heilmann.

f the far-famed Connecticut Valley,[6] for here there is a prousion of trails of creatures great and small, quadrupeds and ipeds, may of which were long of limb, compact of foot, and mpress one as being concerned with weighty matters—quesions of food or safety which would brook no delay. In everal instances the quadrupedal resting posture is clearly ndicated by a creature whose normal gait is that of a biped, ut in no instance is the impressed hand that of a carnivorous r theropod dinosaur, whose sharply curved grasping talons orne on the fore limbs would have left a highly characteristic mpression such as is never seen. That carnivores were presnt is an irresistible conclusion, and the inference is that certain umerous footprints made by the hind feet only, in which the laws, including that of a grasping hallux, were comparatively harp, are attributable to such forms. That aridity does give ise to bipedality is evidenced by the present existence of everal bipedal lizards, notably in our own Southwest, and in ustralia where the frilled lizard, *Chlamydosaurus,* reaches length of five feet and is exceedingly swift of foot.

Rise of sauropod dinosaurs. Climatic oscillation during the urassic gave rise to humid conditions and this, coupled with xtensive low-lying delta lands along the shores of shallow eas, tempted certain of the increasingly large Theropoda to orsake the strenuous life of a carnivore for the slothful ease f an amphibious herbivore. These huge creatures, because f the increased burden of the flesh, had reacquired a quadupedal gait as did the armored dinosaurs (stegosaurs). hey suffered no very great alteration in their dental battery, he teeth of which became spoon-like (*Brontosaurus*) or, colectively, rake-like (*Diplodocus*), fit only for securing some ort of abundant vegetation, not for the rending of flesh. The ate of these forms and that of the armored *Stegosaurus* were curiously linked together, for although unrelated, their habitat and habits seem to have been very similar and their general extinction was apparently simultaneous. What was the physical cause of this extinction, which is believed to have occurred in the Lower Cretaceous (Comanchian), we do not know, for there is little evidence of climatic change. It may have been a temporary restriction of habitat, but curiously enough, these dinosaurs managed to survive the uplift at the close of the Jurassic, but *Stegosaurus* is unknown, and the sauropods extremely rare, except in remote regions such as Patagonia, after the much less extensive Lower Cretaceous movement.

---

[6] See Lull, R. S., "Triassic Life of the Connecticut Valley." *Connecticut State eol. Nat. Hist. Survey,* Bull. 24, 1915.

All of the most impressive characteristics of both Sauropoda and *Stegosaurus*, huge size, small brain, and, in the latter, great upstanding plates and spines, are to the paleontologist indications of the overspecialization which he interprets as racial senility. With such forms these characteristics, when coupled with a long period of adolescence and the consequent slow breeding which may safely be inferred, render their extinction imminent.

Gadow,[7] in speaking of the habits of recent crocodiles, says: "In cooler countries they hibernate in the ground; and in hot countries, which are subject to drought, some kinds æstivate in the hardened mud; or they migrate. When, during a prolonged drought on the island of Marajó, at the mouth of the Amazon, the swamps and lakes were dried up, the alligators migrated towards the nearest rivers, and many perished in the attempt. On one farm were found 8,500 dead, and at the end of Lake Arary more than 4,000. Such occurrences in bygone times may perhaps explain the masses of bones found here and there in a fossil state."

From this it will readily be seen how small a climatic change might account for the serious depletion of an army of huge forms, perhaps never very numerous as to individuals, and

---

[7] Gadow, H., "Amphibia and Reptiles." Cambridge Natural History, vol. 8, 1909, p. 447.

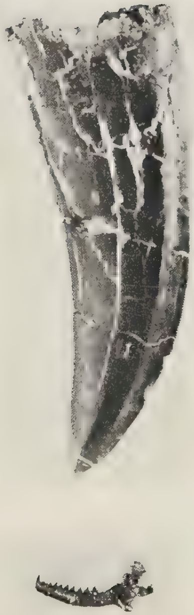


FIG. 25.—Tooth of a carnivorous dinosaur, *Allosaurus*, and (below) jaw of a contemporary mammal, *Dicrocynodon*. Originals in Yale University Museum. From Lull's "Organic Evolution," published by the Macmillan Company.

his may have been just enough to give the final death blow to
n expiring race.

Final extinction of dinosaurs. In the later Cretaceous the
mphibious habitat was again widespread, if indeed it was
ver seriously diminished after its first expansion in the Jurasic, for here we find the final efflorescence of dinosaurs. The
auropoda and Stegosauria had largely gone, but in their
laces were unarmored duck-billed dinosaurs or trachodons,
airly rapid runners ashore but, judging from webbed feet and
ompressed tail, as quick as crocodiles when circumstances
orced their retreat to the waters. Heavily armored dinoaurs, the nodosaurs (ankylosaurs) were present, as were
e horned Ceratopsia, some of which were highly grotesque
eings. And to maintain the balance of power there were
arnivores, both small and great, the latter the mightiest beasts
f prey which ever walked the earth. Then comes their
ramatic extinction, the world over, although they may have
st their world-wide dominance some time before, as we
now these late Cretaceous forms only from Patagonia, Monolia, a few European localities, and western North America;
ut there they were in the climax of their grandeur and there
little save the tendency to overspecialization once more to
arn the observer of their coming dissolution. But so far as
ur records go, not one dinosaur of all the hosts that were
rvived the Mesozoic, for undoubted post-Cretaceous rocks
ave not yielded a fragment of their remains.

Why they became extinct no one knows. Our chart shows
lowering of temperature toward the close of the Cretaceous,
d to such climatic changes reptiles are highly sensitive.
owever that may be, the great Laramide revolution which
arks the close of the Mesozoic must have brought in a long
ain of attendant events in consequence of which the dinoaurs perished. Of all factors of which we have knowledge,
e draining of the low-lying coastal lands, with a consequent

obliteration of the amphibious habitat, seems to have been the most significant. Dinosaurs have been spoken of as associated with peneplanation and the times of their expansive evolution seem to be coincident with periods of degradation rather than with diastrophism, the latter having a restrictive influence.

Rise of mammals. Perhaps the most remarkable thing which the history of the Mesozoic brings forth is the immense period of evolutionary stagnation on the part of the mammals. They are first actually recorded in the Upper Triassic rocks of rather remote localities, Germany and South Africa, and are already differentiated in dietary habits. During the Mesozoic, they develop in numbers and in tooth specialization. They do not, however, increase markedly in size, but are humble folk, so far as our records have revealed them, until the extinction of the dinosaurs has been accomplished. One cannot but associate the idea of mammalian suppression with that of dinosaurian dominance in the relation of cause and effect, unless it shall some day be revealed that the mammals were undergoing a marked evolution beyond the temperature-limited habitat of the reptiles. That the former showed no marked evolutionary advance in the place where the dinosaurs actually occurred is an attested fact, and the significance of the dinosaurian check is no more graphically shown than by two specimens in the Yale Museum. These are both of Morrison age (Jurassic), from what is known in our records as Quarry 9 at Como Bluff, Wyoming, a locality which has produced a number of the rare mammalian specimens. The striking thing, however, is the association of these mammal jaws, especially the type of *Dicrocynodon* Marsh, with the tooth of a carnivorous dinosaur, possibly *Allosaurus*. The figure here reproduced (Fig. 25) is from a simultaneous photograph of these two specimens, which are therefore on exactly the same scale. The single dinosaurian tooth greatly exceeds not only the tooth of the mammal, but the containing

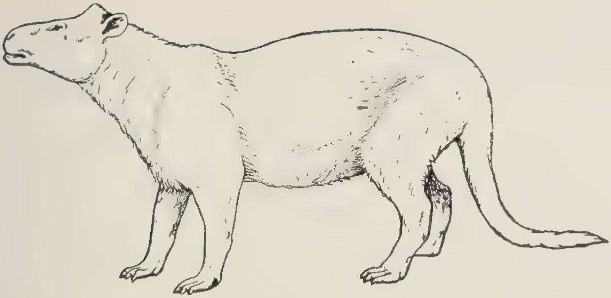


FIG. A

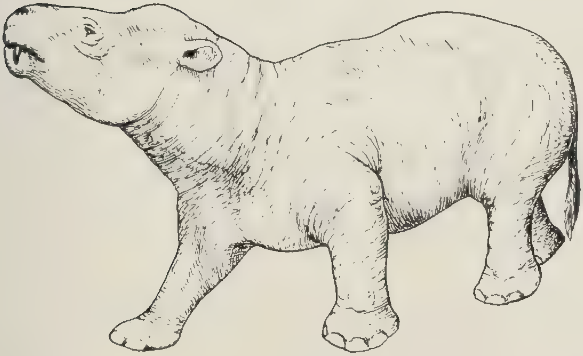


FIG. B

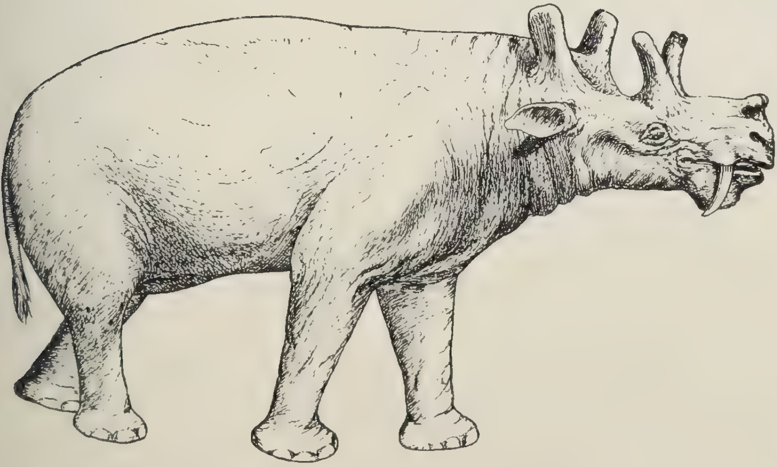


FIG. C

PLATE V.—Restorations of archaic mammals. A, cursorial type, *Phenacodus primævus;* B, swamp-dwelling amblypod, *Coryphodon;* C, four-horned amblypod, *Dinoceras,* the culmination of its race. After Lull.

jaw or even the entire creature as the imagination conjures it up.

The archaic mammals. Dinosaurian extinction heralded the expansion of the mammals, and thus the basic cause of the overthrow of the reptilian dynasty, the Laramide revolution, was the enabling act in the evolution of the higher race. Nature now began once more to people land and sea with beasts of diverse sorts, both small and great; but it was only the warm-blooded furry forms whose privilege it was thus to expand.

The first attempt, following hard upon the dinosaurian extinction, proved to be brief of duration, as though Nature took the stock she had at hand without waiting for the coming of more plastic types. These creatures of the first mammalian expansion have been called archaic, in that while capable of a certain degree of specialization, they were more or less static in three very essential structures, feet, teeth, and brain. Certain of them were herbivores, some light-limbed, fairly speedy, suggestive of the later cursorial ungulates, although never attaining perfection as speed-adapted types. These were the condylarths (Pl. V, A). Others were slow-moving, ponderous forms relying upon weapons rather than upon fleetness for defense. Among these latter, the amblypods, were the swamp-dwelling *Coryphodon* (Pl. V, B) and the later Dinocerata (Pl. V, C), with conservative molar teeth and feet and absurdly small brain, coupled with elephantine bulk and proportions of body and limbs, but with what was superficially a highly specialized skull having many horn-like prominences and sabre-like canine teeth—a veneer of specialization over a primitive type.

The flesh-eaters were in some respects better equipped than their plant-feeding contemporaries, but they, like the others, were, if one may judge from skull capacity, notoriously dull and stupid compared with the shrewdness of their modern supplanters (Fig. 26).

Incursion of the modernized mammals. The archaic mammals barely survived the Eocene, only one group, the hyænodonts, being found in Oligocene rocks. Early in the Eocene, however, are seen the vanguard of an army of invaders, none of which seem directly related to the native mammals. Their simultaneous appearance in North America and Europe points to a contiguous center of evolution somewhere to the north, either a circumpolar land or the northern part of what is now Asia. Here they underwent their primal evolution and here they were endowed with the highest potentialities along the three directions wherein the archaic mammals failed. Climatic oscillation in the north in the early Cenozoic drove these modernized mammals south along the three continental radii, not all at once, but in a series of drives, until the competi-

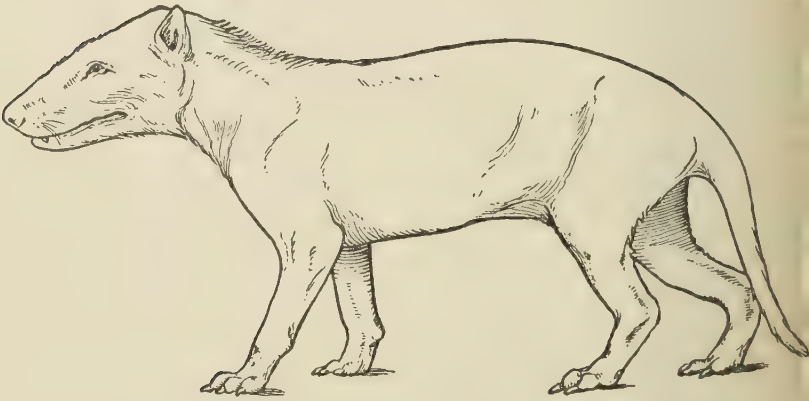


Fig. 26.—Restoration of the creodont, *Dromocyon*. After Osborn, from Lull's "Organic Evolution," published by the Macmillan Company.

tion became too severe for the native inhabitants to endure. Assimilation of the native stocks by such an invading army is impossible among animals, however it may be with mankind. The archaic mammals, therefore, had but little choice. Some lingered on, enduring the competition until it became greater than they could bear, others may have migrated still farther south to find asylum, which served to postpone their inevitable fate. Yet others, a very few, may have evolved into higher types, such as the family Miacidæ of the archaic carnivores, although whether they deserve the stigma of genetic relationship with the other archaics in view of this potentiality is somewhat doubtful.

Rise of grazing mammals. The modernized invaders are now established in their kingdom; they are the early odd-toed ungulates—horses, rhinoceroses, tapirs; the even-toed ungulates, such as camels, deer, and swine; the rodents; the carnivores, insectivores, and primates; and in the Old World the proboscideans or elephants and mastodons. Continental elevation in Europe and more especially in Asia during the Miocene brought in its train a marked increase in aridity which in turn had a more or less profound effect upon the flora of the temperate zones, for it meant a diminution of shrubby and herbaceous plants and a wide expansion of the harsher grasses, which now become the dominant note in the world's flora.

This could not but affect the mammals most profoundly, especially the hoofed forms. Floral differentiation during the Oligocene had already made its impress upon certain groups, such as the horses, so that they in turn were differentiating along several lines, some with short-crowned teeth suited to tender herbage, others with grinders whose length and complexity forecast the grazing teeth of their successors and whose dietary choice led in the direction of the coming grasses. Then came the floral change of the Miocene and with it a rapid expansion of grazing forms—horses, camels, deer—and the restriction and often the extinction of browsing types. It is true that browsing forms are still extant, but not in their old profusion nor in their old homes, while the grazing forms are numerous and characteristic of the widespread steppes the world over.

Origin of man. We have observed the influence of geologic change in the evolution of the brute, and we have now to inquire whether mankind in his long upward course has been amenable to those same laws or whether he has been a thing apart from other forms of life, whose development has been controlled by other influences. As the primates, the group to which mankind belongs, are to be classed with the modernized mammals, their course of evolution up to the point of their differentiation as primates must have been one with all the rest and hence the result of the same chain of causes. And their differentiation from the other mammals when they came to the parting of the ways seems to have been due to the departure of the latter from their primal mode of life and structure rather than to any special evolution of the primates themselves, for in many ways they are among the most primitive of the modernized hosts, and their tree habitations may well have been a very ancient habitat of the whole mammalian race.[8]

They throve in their northern home just as did their other compatriots, and like them drove southward along the several continental radii, the rear guard drawing in toward the equator with the northern limits of the tropical forests within which they dwelt and upon which, with rare exceptions, they are dependent to this day for food and safety. They reached North America, as the map (Fig. 27) indicates, early in Eocene time (Wasatch) and became so abundant as to form a high percentage of certain fossil faunas. Here they throve until the close of the Eocene, when they died out, and North America knew no more primates until the coming of man. They had, however, crossed the isthmian land-bridge or its equivalent into South America, where they still persist.

---

[8] Matthew, W. D., "The Arboreal Ancestry of the Mammalia." *Amer. Nat.*, vol. 38, 1904, pp. 811-818.

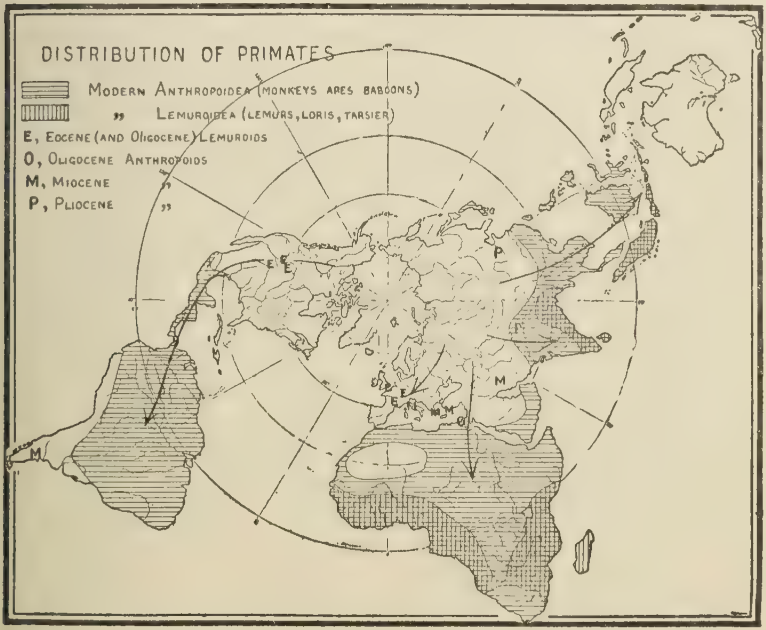

DISTRIBUTION OF PRIMATES
Modern Anthropoidea (monkeys apes baboons)
„ Lemuroidea (lemurs, loris, tarsier)
E, Eocene (and Oligocene) Lemuroids
O, Oligocene Anthropoids
M, Miocene „
P, Pliocene „
E
E
P
M
E
M
M

Fig. 27.—Map showing the geographical distribution of the primates, living and extinct, and their indicated dispersal from Holarctica. After Matthew, from "Problems of American Geology," 1915, published by Yale University Press.

In Europe, the history of primates below man was similar to that in North America, marked by Eocene abundance and synchronous extinction, but during the Miocene, at the time of the proboscidean migrations, they reappeared, probably from Africa, to suffer a second extinction during the Pleistocene. While the sub-human primates are now extinct on the Asiatic mainland north of the great Himalayan uplift, they still persist in tropical Asia, in India, Indo-China, the East Indies, Japan, and the Philippines. They are also extant in tropical Africa.

Anthropoid apes. Man's nearest blood relatives, whatever may be his prejudice in the matter, are the so-called anthropoid or man-like apes: the orang, chimpanzee, gorilla, and gibbon, all descendants from the same stock which gave rise to humanity and perhaps fallen to their present condition through being the victims of circumstances. That man owes his higher estate, at least in part, to his past environments we shall endeavor to show.

Of the great apes, the orang-utan is one of the most familiar, for it and the chimpanzee are the kinds most frequently seen in captivity. The orang is readily distinguished, however, by its reddish hair. It is rarely more than four feet tall but is relatively of great girth, which, together with an arm spread of upward of seven and a half feet, gives it a remarkable appearance. The jaws are powerful, with large canine teeth, but the hands are the chief weapons of defense. The great size of the orang renders it less agile than the gibbon, for instance (see page 141), and it climbs somewhat laboriously as does a man. It is highly intelligent but sluggish, stirred to action only by some powerful incentive such as hunger. Orangs are today confined to the dense somber forests of Borneo and Sumatra, but the fossil remains of their ancestors come from the Siwalik Hills on the Asiatic mainland and thus betray the course of their migration.

The chimpanzee and gorilla are both African in distribution, although also of Asiatic stock. They are perhaps the nearest to mankind in blood relationship. The chimpanzee may readily be distinguished from the orang by its black hair. It is also taller, although never exceeding five feet, and is less bulky

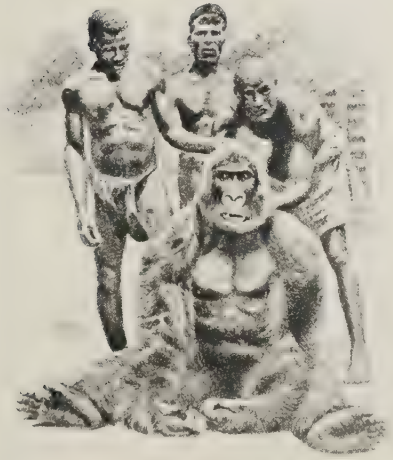


FIG. 28.—Gorilla, *Gorilla gorilla*. From "The American Natural History," by William T. Hornaday; copyright, 1904, 1914, by William T. Hornaday; published by Charles Scribner's Sons.

ınd hence more active, swinging from tree to tree by the hands vith great agility. They rest in the sitting posture, sometimes tand or walk, but run on all fours. Jaws and teeth are their hief defense.

The gorilla (Fig. 28) is by far the most formidable of all he great apes, for it has huge size and strength. An authentic ecorded size makes the gorilla five feet one and one-half nches tall and 418 pounds in weight. Its lower limbs, while normously powerful, are disproportionately short. If the imbs bore a human proportion to the torso, the creatures vould stand at least seven feet in height, with a weight of alf a thousand pounds! The huge size of this ape has forced to become largely terrestrial, but instead of becoming more ıan-like as an adaptation to ground-living, it has taken a yet ıore brutal aspect, more like a bear than a human being.

All of these apes, the orang, chimpanzee, and gorilla, are egenerating from the higher condition of their common ncestor with mankind; the chimpanzee least, the gorilla most f all. The gibbons (Fig. 29), however, of which there are everal species, although the most remote from mankind in ctual relationship, have probably retained in greater degree ıan any others the habits and development of the anthropoid tem-form. They are wonderful acrobats, their relatively mall size and immensely long and powerful arms lending ıemselves to the full measure of arboreal progression. The ibbons are oriental in distribution, living in the wooded egions of southeastern Asia and the islands of Sumatra, orneo, and Java.

It were well to dwell for a moment upon the locomotive ıethods of these apes which, instead of running upon the pper side of the branches, as do most arboreal forms, swing eneath them by means of their hands. This method of locomotion has been called brachiation (Lat. *brachium*, arm) and all probability took its rise with the earliest anthropoids, reaching its highest development in the modern gibbon. On the ground, the gibbon walks erect, either touching the knuckles of the hands to the ground or with the arms held above the head. The gait is quick, waddling, with no elasticity of step, and they are soon overtaken. But in the trees they are virtually transformed, for their hand leaps are prodigious, twelve, eighteen, one authority says no less than forty feet being cleared, and that for hours at a time. Fully to appreciate what this means one should compare it with the precise mechanical stride of a racehorse, for whereas in the horse there is a practical uniformity of conditions stride after stride, with the gibbon no two hand leaps can be the same, and each time such a thing is essayed a problem must be solved, for in order neither to over- nor under-shoot the mark, the right amount of force must be used, and this varies with the distance and the ability of the objective branch or branches to bear the creature's weight. Thus, as with a gun pointer, the aim, distance, trajectory, windage, and in addition the varying force, all must be taken into consideration; in the present instance, moreover, the problem must be solved and its practical application brought about instantly, and the penalty for error either in solution or application may be death. Even though the process becomes automatic, the result of much experience, there is, nevertheless, a high premium placed upon mental acuteness, and the weeding out of the unfit is ruthless. Add to this the fact that the hands may be used to bring objects before the face for examination, thus inciting the powers of observation, and two great stimuli to higher mentality are attained. There is reason to believe that the human precursor, before leaving the sheltered life of an arboreal primate, progressed and acted much as do the gibbons, with a consequent quickening of intellect as time went on.

Descent from the trees. But while tree-life had much to do with the prehuman evolution of our ancestors, the arboreal

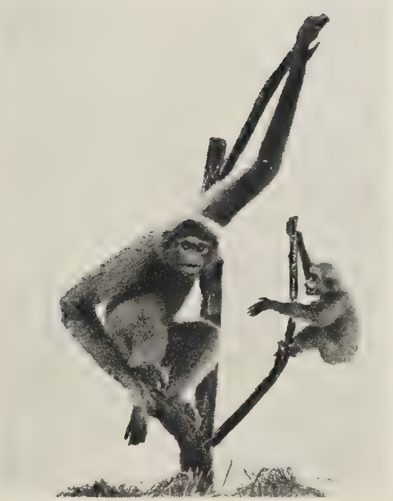


FIG. 29.—Gibbon, *Hylobates lar.*

, after all, a limited environment and the descent to the ter-
estrial habitat was as necessary to further evolution manwards
s was that older emergence upon land on the part of our
iscine ancestry. In the former case as in the latter, the actual
ttainment of the terrestrial habitat is supposed to have been
orced by geologic change of a very similar character. The
resumption is that central Asia was the evolutionary center
f the anthropoids and so far as our records go this is borne
ut by the fossils, the oldest of which are found in the Siwalik
Iills of northern India in rocks of Lower Pliocene age. From
is center of radiation these primates took their departure,
e gorilla and chimpanzee southwestwardly toward the Dark
ontinent, while the gibbons and orang went toward the southast. The prehuman, on the other hand, remained in central
sia nearest the dispersal center, which, we have seen, is
enerally true of the latest and most highly specialized of a
ace. The forms which migrated southward felt the enervatg languor of the tropics and remained static, if they did not
tually retrogress, whereas the prehuman in the more invigrating and variable climate progressed in his evolution toward
higher type. Central Asia has proved to be the theater
herein the highest mammalian evolution could be attained,
or here the forms which man has chosen for his companions,
e domestic animals, almost without exception attained their
volutionary completion.

The actual descent from the trees seems to have been due
a chain of events which in many ways parallel those which
npelled the emergence.[9] The Miocene uplift, with the conequent aridity, has been mentioned. As a direct result, the
upendous barrier of the Himalayas began to arise, cutting
ff the forests of central Asia from their old-time continuity
ith those in India, and thereby severing the lines of com-

---

[9] Barrell, J., "Probable Relations of Climatic Change to the Origin of the
ertiary Ape-man." *Scientific Monthly*, January, 1917, pp. 16-26.

munication by which the anthropoids had left the cradle of their evolution. Miocene and Pliocene aridity diminished the northern forests, as Devonian aridity had diminished the terrestrial waters, until finally there were detached wooded areas within which the contained primates were as isolated as is the orang on sea-girt Borneo and Sumatra today. Further diminution compelled the descent to the ground on the part of the larger and more intelligent forms among them and the destruction of such as could not meet terrestrial competition. Thus a man-like tree-born primate became an earth-borne creature which from sheer necessity ultimately arose to man's estate. This meant the assumption of the erect posture and the lengthening and strengthening of the lower limbs for speed, while the hands, released from the fetters of their earlier locomotive function, became the organs of the mind. Now man had to compete with the mighty carnivores, and as nature had ill endowed him with defensive weapons he had to devise crude armaments of stick or stone with which to insure his survival. The dwindling forests, especially as their tropical character had gone, no longer supplied an easily gained livelihood, and sustenance had to be sought from other sources, mainly from among the feebler of man's fellow creatures. It is probable that he also utilized the seeds of grasses which grew along the margins of the forests, the ancestors of our domesticated grains.

Increasing severity of winters, prophetic of the Glacial Period, necessitated some further means of keeping warm, and man utilized for clothing the skins of beasts which he had slain and later harnessed fire to his use. In common with the other primates, the precursors of mankind were doubtless gregarious, probably submitting to the leadership of such as by strength or cunning could enforce their authority, but not until the terrestrial life was attained was the higher communal life with coöperative division of labor possible.

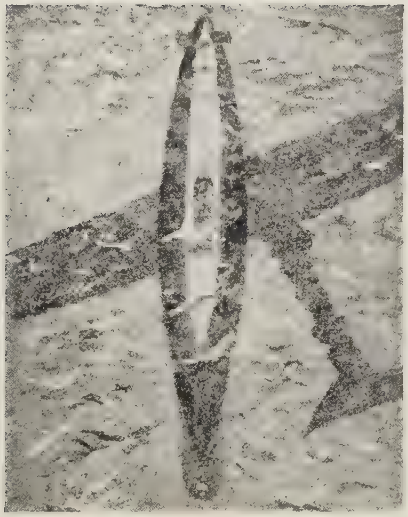


FIG. 30.—Photograph of a submarine, twenty feet below the surface, taken from the aeroplane whose shadow is shown in the picture. From *London Illustrated News*.

By means of this coöperation and his individual prowess man has attained dominion over the organic world, while through his subduing of nature's forces he conquers all of her varied realms from the equator to the poles, adapting himself to environments which mold their creature denizens most profoundly and through which he passes unimpressed by the aws which compel their adaptation, for he is swifter than the eagle in his flight and he passes through the waste of the waters unscathed by nature, a victim, if such he be, only to others of his own kind (Fig. 30).

SUMMARY

As the physician, by a clever device, can record graphically the pulsations in the blood stream which are synchronous with the throbbing of the human heart, so I have drawn a curve to show the correspondence between the pulse of life and the heavings of the earth's broad breast. In this curve (Fig. 14) the evolutionary crises and periods of expansive evolution are represented by upward movements, while extinctions are indicated by the downward plunge of the racial line. This curve s broken where as yet we have no tangible evidence to validate our theory, solid when the fossil record changes theory into fact.

Thus the first recorded crisis, the origin of vertebrates, is drawn coincident with the revolution at the close of the Proterozoic era, but the actual vertebrate record begins in mid-Ordovician time at the numeral 1. The development of lungs s connected with the disturbance at the close of the Silurian uplift, the first recorded lung-fishes appearing at the numeral 2, n the Lower Devonian, while the first footprint at 3, in the Upper Devonian, completes the evolutionary movement. The Mississippian is a time of expansive evolution of the stegocephalians, while the establishment of the reptiles was the result of aridity toward its close, hence synchronous with the

Ouachita uplift. The culmination of the wide disturbances a the close of the Pennsylvanian brought on aridity and glaciation in the Permian, with the beginnings of the warm-bloode stocks, birds and mammals, although the first recorded bir at 7 is Upper Jurassic and the first known mammals at 6 Uppe Triassic. Aridity has been regarded as the chief incentiv to dinosaurian evolution, the actual record at 5 beginning i the Lower Trias. The differentiation of the Sauropoda, response to the expansion of the amphibious aquatic realm may have been Triassic, but in greater probability the subsidence which followed the Palisade diastrophic movement lat in the Triassic may be nearer to the actual time. They firs appear in the Lower Jurassic, but do not culminate until th early part of Lower Cretaceous time, shortly after which the suffer partial extinction, although lingering on in diminishe numbers in more remote portions of the globe. The othe dinosaurs gradually increase in numbers, size, and specialization, until the close of the Cretaceous, when, with the movements which culminate in the Laramide revolution, the plunge into extinction.

The curve of mammalian evolution is perhaps the mos striking of all, consisting as it does of minor fluctuations whic may represent accident of preservation and recovery rathe than periods of evolutionary expansion, as is equally true of th dinosaurian curve. Then with the Laramide revolution an the coincident dinosaurian extinction comes the rapid mammalian deployment, the archaic mammals, first known in the basa Eocene at 9, becoming fewer and less important, althoug increasing in specialization until their final extinction in th Middle Oligocene. With the fluctuating climate of the northern area come the modernized forms, first known in the Lowe Eocene at 10, then the differentiation of browsing and grazin forms, followed by a restrictive evolution of the former an a wide expansion of the latter consequent upon the Miocen uplift and its resultant aridity. While the primate line is solid e derived human line is broken to the point 11, the first tual record of man; the descent from the trees is, however, ade coincident with the Himalayan uplift and with the in-easing aridity of the Miocene.

Man's intellectual and spiritual rise and his dominance over e forces of nature and over the brute creation are shown aphically by the height to which his line ascends above the ghest crest of the evolutionary crises which have gone before. or this dominance the Cascadian revolution with its recurrent eriods of devastating cold, out of which we are emerging, ust be looked upon as a contributory cause.

Thus time has wrought great changes in earth and sea, and ese changes, acting directly or through climate, have always und somewhere in the unending chain of living beings certain oups whose plasticity permitted their adaptation to the newly ising conditions.

The great heart of nature beats, its throbbing stimulates the lse of life, and not until that heart is stilled forever will the ythmic tide of evolution cease to flow.

CHAPTER V

THE ANTIQUITY OF MAN

RICHARD SWANN LULL

STERLING PROFESSOR OF VERTEBRATE PALEONTOLOGY, YALE UNIVERSITY

THE Mosaic account of the creation, which has been and is yet of wide acceptance, would give us a very recent date for man's advent on this planet. The strictest interpretation of this account is that of Doctor John Lightfoot, a profound Biblical scholar, vice-chancellor of Cambridge University in 1654, who is often quoted because of the exactness of his findings. As a result of careful searching of the Scripture, Doctor Lightfoot was led to declare that "Heaven and earth, centre and circumference were made in the same instance of time, and clouds full of water, and man was created by the Trinity on the 26th of October 4004 B. C. at 9 o'clock in the morning."

One questions, however, not the Scriptural account but the exactness of its interpretation. The researches of oriental scholars are bringing more and more into evidence the historical truth of the Old Testament narratives, and are establishing from other lines of evidence the historical character of Abraham, Isaac, Jacob, and the other Hebrew patriarchs, but they are also tracing back into a more and more remote period the history of the Near Eastern peoples, as the result of the extensive excavations, with their treasure trove, which are being carried forward in these venerable abiding places of mankind.

Among the most interesting of these finds has been the bringing to light of several tablets, one of which is preserved n the Yale Babylonian Collection, and which constitute the oldest human documents thus far discovered. These several ablets are of black stone, of no very great size, but bear engraven on their surfaces characters which give to us a message out of the past, the time of which antedates that of Christ by ome 5,500 to 6,000 years; in other words, a thousand or more ears before Doctor Lightfoot's date. Nor is this all, for the nscriptions are no longer in the so-called picture writing or deographs, but in a form of writing undoubtedly derived from his. They have progressed so far along an evolutionary pathway that the original pictures cannot in some instances be even guessed at. This, it would seem, implies a centuries-long developmental period before the beginning of inscriptive writngs, and the inference is also justifiable that the protoscript ould not have been invented but by peoples of considerable ntellectual powers who had long since emerged from savagery nd were vastly further yet removed from their ultimate eginnings.

Another line of evidence is cultural, based not on inscripions or documents of any sort, but upon the implements and weapons of vanished peoples, with their varying degrees of refinement. (See Chapter IX.) Historic times begin with written records; the prehistoric era begins with the Old Stone Age and continues, in Europe at least, through the New Stone Age, the Bronze Age, and the Iron Age. The Stone Age, as ust noted, has its subdivisions into, first, the New Stone Age or Neolithic period, in which the distinctive characteristic of the mplements is that some of them at least were rubbed smooth or polished after the preliminary fashioning was completed. Back of this period lies the Paleolithic, varying immensely in he degree of perfection of use and workmanship, so that archeologists are agreed upon a number of cultures (see able, below), based upon distinctions some of which are evident to the most casual observer, while others are discernible largely to the expert only. Back of the Paleolithic lies the Eolithic, or Dawn Stone implement period, the definition of which originally implied that the stone implements of that time were not artifacts in the sense of purposeful manufacture, but merely pieces of stone of convenient size which showed the effect of use. Later authorities admit of the presence of certain retouching on the margins of implements they still call eoliths, although just where they would draw the line between eoliths on the one hand and paleoliths of crudest workmanship on the other is not clear. Yet other authority would disclaim any human association with these eoliths, either of use or manufacture, and invoke the physical forces of nature to account for their seeming. But our purpose is not to tell again the arguments, but merely to establish, if possible, on the basis of such evidence, a further criterion for the testing of man's antiquity. It becomes at once evident, however, that all races of mankind are by no means in the same degree of cultural advancement at a given time, and that for ages of human history the relatively static and the highly advanced peoples must have dwelt contemporaneously in divers portions of the earth; just as, for instance, the native Tasmanians, of whom the last survivor died in 1877, were in a state of culture which some have called Eolithic and others a middle stage of the Paleolithic, perhaps Mousterian. It becomes necessary therefore to confine ourselves to some definite region which has been the home of mankind from remote ages, in order to establish a chronological series. There is no doubt in my mind that in the course of time certain portions of Asia will provide us with a chronology of great interest and amazing antiquity, but thus far our knowledge of European cultures is at once the most detailed and the most accurately dated, and the one with the fewest omissions in the series. There are readily applied checks on the European chronology, for it has been synchronized very accurately with the successive advances and retreats of the ice in the Pleistocene glacial epoch, as well as with the recorded changes in the faunæ of these several tages. Hence the European cultural chronology has become the standard for the world, and as it is further possible to synchronize the periods of glaciation in the Old World and in the New, a comparative chronology for the latter may some day be established.

CHRONOLOGICAL TABLE[1]

Ice Age Chronology			Cultural Chronology			Human Species
	Holocene (Recent)	4 Post-Glacial	Iron Age			*Homo sapiens*
			Bronze Age			
			Neolithic		Campignian	
			Mesolithic		Maglemosean	
					Azilian-Tardenoisian	
QUATERNARY	*Pleistocene*	IV Glacial (Würm)	*Paleolithic*	Upper	Magdalenian	
					Solutrean	
		3 Interglacial (Riss-Würm)			Aurignacian	Crô-Magnon Man
				Lower	Mousterian	*Homo neandertalensis*
		III Glacial (Riss)				
		2 Interglacial (Mindel-Riss)			Acheulian	
		II Glacial (Mindel)			Chellean	*Homo heidelbergensis*
		1 Interglacial (Günz-Mindel)				*Eoanthropus dawsoni*
		I Glacial (Günz)			Pre-Chellean	*Pithecanthropus erectus*
TERTIARY	*Pliocene*		*Eolithic*		Foxhallian	
					Ipswichian	
					Cantalian (?)	

---

[1] Modified from MacCurdy.

But Europe is not supposed by most authorities to have been the original evolutionary center of mankind; its small size seems to preclude that. Rather is it a place to which, as in historic times, migrating hordes came from time to time when force of circumstances drove them out of Asia and perhaps more rarely from Africa. That Asia is the birthplace of mankind is seemingly established, the following being some of the evidences for this belief.

Asia possesses great size, and hence varying life conditions, together with a central location contiguous to all other land masses, even, as the north polar projection shows (Fig. 31), to North America. From Asia, as from no other of the continents of the world, is communication so easy and the migratory routes so clearly discernible. Asia is the home of the highest and best of the higher organic life and is with few exceptions the place whence man has derived his dependents and allies, the domestic animals and plants. Asia is the seat of the oldest civilizations, many indications of which, though visible as sand-drifted ruins, have outlived the vaguest traditions concerning their origins. Finally, the physical and climatic conditions of Asia in the Cenozoic era were such as the scientist must postulate in his imaginings of the *modus operandi* of human origin from his prehuman forebears, i.e., such as would enforce descent from the trees and terrestrial adaptation.[2] The fact that the most primitive peoples to-day—African pygmies and Australian blackfellows—are not Asiatic does not tend to controvert but rather to strengthen this belief, for as the first formed ripples of the widening circle caused by a stone dropped into a pool are the outermost, so the descendants of the earliest migrants should to-day be found farthest

---

[2] See Lull, in chapter IV; and Joseph Barrell, "Probable relations of climatic change to the origin of the Tertiary ape-man," *Scientific Monthly*, January, 1917, pp. 16-26.

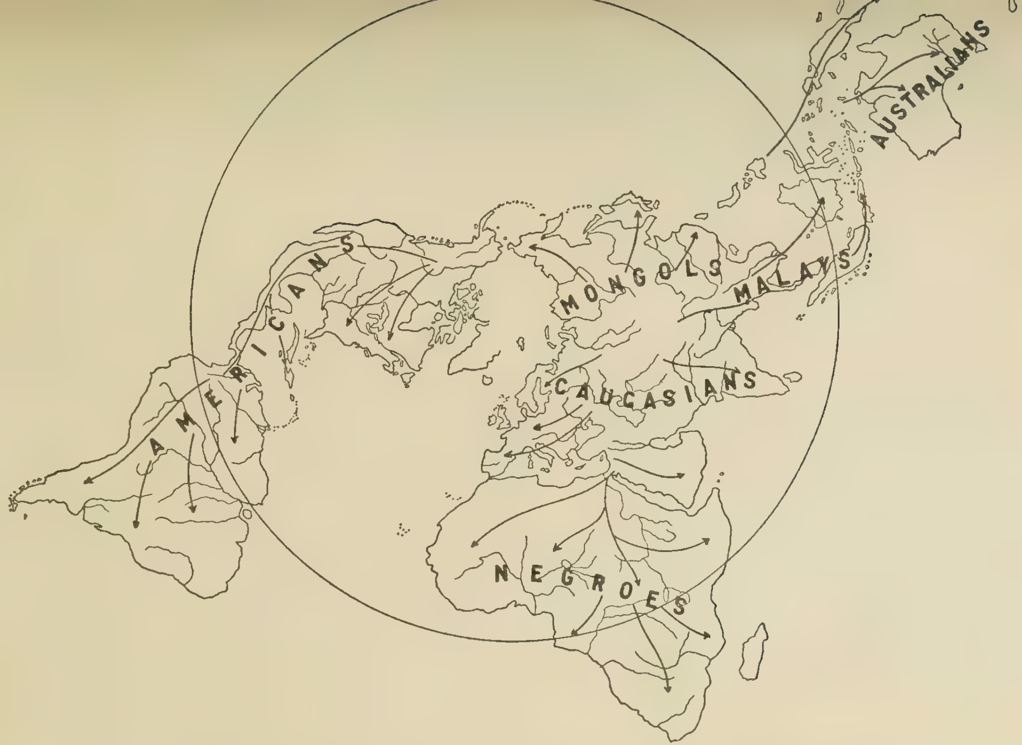


FIG. 31. MAP TO ILLUSTRATE THE BROADER LINES OF DISPERSAL OF THE PRINCIPAL RACES OF MAN

Modified from Matthew.

from the center of origin. The fact that the most ancient human remains in point of time thus far discovered are from Java and therefore nearer the focal point is yet another bit of evidence.

It is with great confidence, therefore, that one looks to Asia, which is now for the first time being systematically explored, to solve by actual findings this age-old problem of human origin.

Fossil Man

Our final and, to the paleontologist, most convincing line of evidence for man's antiquity lies in the discovery of actual remains of human beings which a fortunate combination of circumstances of burial, conservation, and subsequent discovery has brought before us. That these are rare is obvious, for even under the most favorable conditions for fossilization, those of shallow-water marine deposits, it has been estimated that but 1,044 out of each 100,000 different forms that lived are known to us. Can we expect, therefore, that the record of what were evidently largely forest-dwelling creatures whose remains are but rarely preserved and who in this instance undoubtedly had methods of disposing of the dead by burning, possibly by consumption as an article of diet, or by merely casting out to be devoured by beasts and birds of prey, could possibly be as perfect as that of the marine forms? One marvels, not that the missing links in our chain of evidence are many, but rather that we possess any chain at all.

Conditions of preservation. There are but two conditions under which the remains of man are ever found: one, the older and rarer, in the valley sediments of rivers which deposit and scour away and deposit again in time of flood or of tranquil flowing, and occasionally catch and drown the unwary, s they do to-day, to bury their remains under tons of sediients which are subsequently removed and their contents xposed either by natural or by human agencies. The other ource is the underground caverns of Europe and elsewhere—bandoned subterranean river beds which are always to be ound in limestone countries and which, when opened to the ir through the eroding away of overlying materials by rain, rost, and snow, formed an inviting retreat from inclement eather and the assaults of savage beasts. These caverns thus ecame the place of abode and often of sepulture of prehistoric ian, but were evidently not available for his tenancy until comaratively late in time (Mousterian, see table, page 151).

Means of determining antiquity. The criteria for establishig the antiquity of human remains are three. First, the eological age of the strata wherein the remains lie; secondly, ie associated animals or artifacts or both; and third, actual omatological distinctions from existing man. The first must e most carefully weighed, and in general such is the very atural scepticism even among scientists that it is well to have orroborative evidence by unimpeachable witnesses both of the iscovery and the exhumation. It is further necessary very arefully to distinguish between natural deposition of remains nd intrusive burial, such as is often practiced by mankind, hich places the subject among objects which may far anteate it in time. A scattered skeleton and one overlaid by absoitely undisturbed deposits are both good criteria of contemoraneity, but chance often makes strange bedfellows. Thus ie finding by the writer of a glass bottle, bearing all the iarks of extremely recent manufacture, *beneath* the hip bone f an extinct horse in an apparently undisturbed Pleistocene eposit in Texas was a little disconcerting until the looseness f the surrounding sand betrayed a filled-in animal burrow ito which the bottle had undoubtedly been thrust. The association therefore with extinct animals and even an apparently like degree of fossilization are not entirely trustworthy when taken alone. Associated artifacts when implying ceremonial burial are fairly safe criteria and have been given high value in European age determination.

The final criterion, that of anatomical distinction, is of course highly valuable, but has led to difficulties, as, for instance, when a modern type, such as all the American ones prove to be, shows other indications of great antiquity. It was formerly supposed that there was but a single line of phyletic descent to modern man, but the belief is gaining ground that, as in the evolution of horses, the story is not so simple as was at first supposed, but that there were several lines of descent all of which may be of ancient origin, so that what have been called modern types of mankind might well be found contemporaneous with, or even antecedent to, the remains of more primitive races. This will be discussed in greater detail below (page 183).

Record of Discovery

New World. A brief *résumé* of the discoveries of the actual osseous remains of prehistoric man which have thus far come to light emphasizes the antiquity of his world-wide distribution, but we are not yet in position to date with finality the earlier men of the New World. Of these, North America has produced a number of specimens, the oldest of which in time of discovery is the so-called Calaveras skull, found, together with certain implements, stone mortars and pestles, spearheads and hammer stones, embedded in Californian gold-bearing gravels of undoubted Pliocene age. How this material came there is a mystery, but at present the Calaveras man is not supposed to have been contemporaneous with the gravels but to represent a man both physically and culturally of much later date.

Again and again such specimens have come to light, as in he Trenton gravels which date from the final retreat of the ce, the Nebraska loess man near Omaha, the Lansing man, nd that of Vero, Florida, where the remains of like degree f fossilization with their animal associates were found enombed with creatures of undoubted Pleistocene affinities. Still ther finds are those at Rancho La Brea in the Pleistocene sphalt of California, and lastly at Dallas, Texas, in the agow sand pit, associated with a Pleistocene fauna recently escribed by the writer. Not one of these, despite their fullment of every other prerequisite to antiquity—burial in older trata, animal association, like degree of fossilization, and o forth—meets the requirements of the physical anthropoloist, for none shows somatological characters which are not ossessed by the modern American Indians. This leads octor Hrdlička to doubt their antiquity, but a growing coniction in the author's mind, stimulated by so high an authority s Sir Arthur Keith, of the Royal College of Surgeons, Lonon, is that, on the other hand, they may in part be of genuine leistocene age and hence point to the high antiquity of the ndian type.

The South American record is comparable. Florentino meghino (1912) described supposedly human forms under ne names of *Tetraprothomo* and *Diprothomo,* based upon emains which in at least one instance owed their peculiarity to ne fact that they were not even human. But in no event were nese so-called men as old or as primitive structurally as meghino would have us believe, and his thesis that South merica may have been the radiation center of the human ock seems untenable.

If none of the New World men are of archaic cast, their ssociation with extinct forms, as for instance with the mastoon and extinct bison in the north and with ground sloths in the outh, seems to bear the mark of authenticity. The most authentic northern instance is that described by the late Doctor J. M. Clarke, of the association in Attica, New York, of mastodon remains with charcoal and pottery. Four feet below the surface, in a black muck, Clarke found the bones of the mastodon, and twelve inches below this, in undisturbed clay, pieces of pottery and thirty pieces of charcoal. The association of the mastodon with the charcoal is not so significant, as it is conceivable that charcoal may have been formed by natural means, but not the pottery. The issue of the magazine *Natural History* for November-December, 1921, figures what seems to be the crude outline of a mastodon on a piece of bone from Jacob's cavern, Pineville, Missouri, in a way comparable to the Upper Paleolithic engravings of Europe.

In South America, again, the association of man and the ground sloth, *Grypotherium,* in a cavern at Consuelo Cove, Last Hope Inlet, Patagonia, seems definitely established. The fresh-looking remains, shreds of skin which show indications of having been cut with primitive knives, the presence of apparently cut grass, all point to the cherishing by man of what were probably the last of these creatures, either in the rôle of domestic animals or of those sacred to some deity as was the Egyptian bull Apis.

Keith is greatly impressed with the diversity of American languages and the high development of pre-Columbian civilizations in the New World, and feels that they point to an antiquity far beyond that commonly accepted by the ethnologist. On the other hand, all indigenous New World men are of essentially the same general racial type, the Mongoloid, nor have they been here long enough to establish racial differentiation comparable to that of the Old World.

Old World. Africa has been productive of but two osseous specimens of man of marked antiquity. One, found at Oldoway ravine, Tanganyika Territory, in the early days of the

Great War, is impressive neither for its apparent age nor its somatological peculiarities. The latest find, however, from Broken Hill mine in northern Rhodesia, has aroused a great deal of interest, because, while not very decisively dated and associated with a recent fauna all of which are either now alive or were so at the coming of white men, the skull itself is of a most peculiar and interesting type, clearly not that of modern man. And the finding of a second specimen which, while fragmentary, serves nevertheless to show community of type with the first, seems to establish the remains as representatives of a race and not due to individual peculiarities.

Arguments striving to prove the ancestral character of the African Bushmen and the fact that Africa may be the primal home of mankind are not yet established theses. Northern Africa in the Barbary States has produced cavern murals comparable to those in southern Europe, and Sollas has made much of Bushman affinities in all of these artistic remains, but these are late in time (Upper Paleolithic, Magdalenian) and do not aid us in our establishment of high antiquity for African man. Undoubtedly Africa is an old, old home of mankind—all signs point to that conclusion—but the actual skeletal remains of types anterior to our own species are, as we have hown, but a single find. This is undoubtedly due largely to paucity of discovery rather than to lack of occurrence.

Of Asia, a similar tale is told, *Pithecanthropus*, found in 1891 in Trinil, Java, the Galilean Neandertal skull, and Peking man constituting the present total, although one looks daily or the announcement of further finds as the outcome of the American Museum's Asiatic expeditions. Again, we simply o not know the country paleontologically.

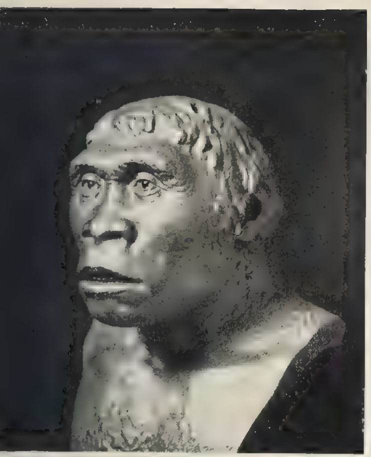
At Darling Downs, Australia, a human skull has been found, pparently in association with extinct Pleistocene Mammalia.

The European finds, on the other hand, are relatively so umerous that as we have established our cultural chronology upon European discovery, so we must base our conception of human antiquity and evolutionary lines largely upon European material. For Europe is small, accessible, and the home of an enthusiastic band of workers whose efforts have been untiring and whose results are already at hand, although much will come to light in the future.

PREHISTORIC HUMAN SPECIES

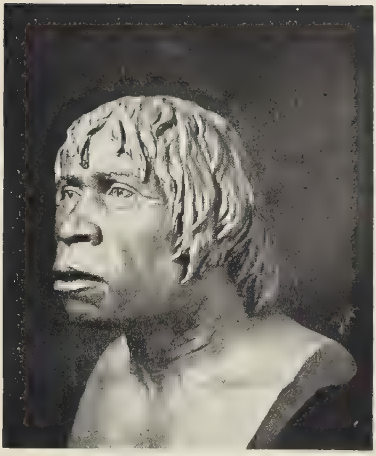
Pithecanthropus erectus

Taken in order of chronological sequence, the Asiatic *Pithecanthropus* stands first, as it does in most respects in the characteristics which it betrays. Found in 1891 in the deposits of the Sula Bengawan, a river near Trinil, on the island of Java, these fragments of humanity are most meager, but such as they are, they throw a flood of light on human origins. Our knowledge is based on Dubois's own admirable researches, together with the widespread replicas of the external aspect of the calvarium, and lately the endo-cranial cast, which have enabled some independent conclusions to be drawn. The remains include the skull-cap, two teeth, and a left femur, the last bearing an exostosis indicative of injury or disease. These probably pertain to a single individual, although they were found scattered through some twenty yards of space and were not all discovered at the same time. This scattering precludes the possibility of intrusive burial, however. The most careful search has failed to reveal any further fragments except a third tooth, brought to light by a special expedition under the direction of Madame Selenka. Previously, however, another very fragmentary specimen, a portion of the lower jaw, had been found twenty-four miles away. So much has been written concerning this type of man that the summary of conclusions, which, however, lack the finality of finished research, is all that need be given here.



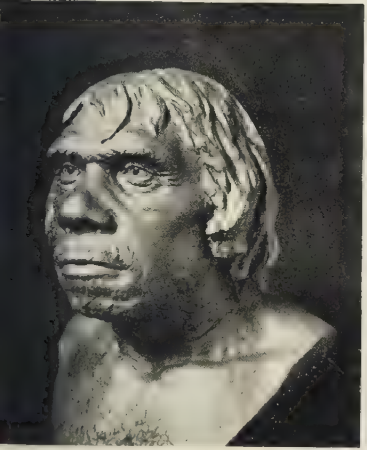
JAVA MAN

Pithecanthropus erectus.



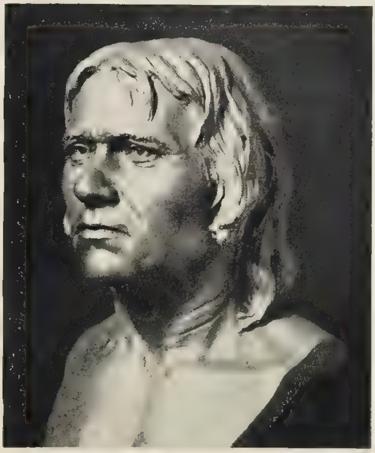
PILTDOWN MAN

Eoanthropus dawsoni.



NEANDERTAL MAN

Homo neandertalensis.



CRÔ-MAGNON MAN

Homo sapiens.

PLATE VI.—Heads modelled by Professor J. H. McGregor, on his restorations of skulls of ancient types of man. These types are not stages in a single evolutionary line, but probably represent four divergent lines. Original models in the American Museum of Natural History, New York.

The skull-cap is dolichocephalic, estimates of the cranial capacity varying from 710 to 1,060 c.c. as compared with 930 to 2,000 c.c. for modern man. The brain, while essentially human in some respects, is very primitive in others, especially in that area in which the memories of past impressions derived from the higher senses are recorded. Whether or not speech was actually used is questioned, but the possibility of it seems clear.

The straightness of the thigh as compared with that of Neandertal man (see page 171) is marked, so that in *Pithecanthropus* the posture may have been nearly as erect as in modern man. In this he is in no sense a transitional form but in skull characters he is, for the shape of the thigh is correlated with that of other parts, the vertebral column with its curves, the pelvis, and the poise of the skull, all of which, one may infer, were distinctly human.

The teeth of the Java man are also of a human type, showing no shortening of the roots or development of the pulp cavity, to which Keith has applied the term "taurodont" (ox-tooth), as in the Heidelberg and Neandertal races to be described later. The alternative type of teeth he calls "cynodont" (dog-tooth), such as those of modern man and the apes, adapted to a more varied and less harsh diet. *Pithecanthropus* had teeth of the latter type. The tooth crowns are wider than long, the reverse of simian dimensions, and although they do show certain minor ape-like characters, they also show certain degenerative features.

Gregory[3] thus sums up the status of *Pithecanthropus:*

> The association of gibbon-like skull-top, modernized human femur and subhuman upper molars with reduced posterior moiety, if correctly assigned to one animal, may perhaps

---

[3] Gregory, W. K., The origin and evolution of human dentition etc., *Jour. Dental Research,* vol. 2, 1920, page 690.

define *Pithecanthropus* as an early side branch of the Hominidæ, which had already been driven southward away from the primitive center of dispersal in Central Asia, by pressure of higher races. But whatever its more precise systematic and phylogenetic position, *Pithecanthropus,* or even its constituent parts, the skull-top, the femur and the molars, severally and collectively testify to the close relationship of the late Tertiary anthropoids with the Pleistocene Hominidæ.

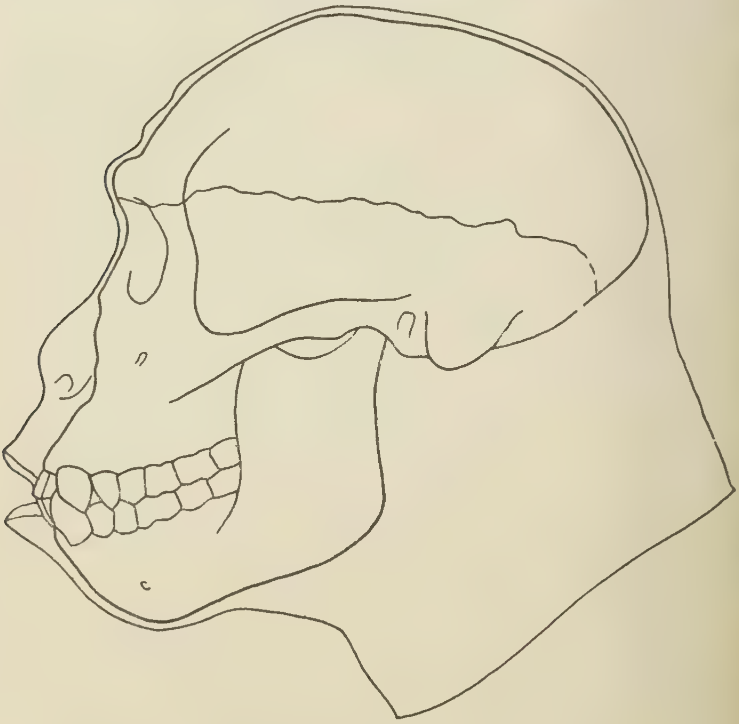


FIG. 32. SKULL AND FACE OF THE JAVA MAN
Pithecanthropus erectus.
Two-fifths natural size. Portion below irregular line restored.
Adapted from McGregor.

Of restorations of *Pithecanthropus,* several have been attempted. The skull completion here shown (Fig. 32) is derived from the studies of Dubois and McGregor. The latter has done an admirable bust based on the most careful detailed study (see Plate VI, page 160).[4]

Pithecanthropus was found associated with twenty-four or more species of mammals, all of which are now extinct and whose affiliations are distinctly Pliocene. Gregory[5] shows this ancient relic as of upper Siwalik age (Pliocene). Dubois considered its assignment to late Pliocene and therefore equivalent to the Cromer forest beds of England (see below). Keith describes its geologic occurrence as follows: under the fossiliferous bed is a stratum of conglomerate, then a layer of clay laid down in quiet muddy water, under the clay a marine deposit containing early Pliocene fossil shells corresponding to the "Crag" of East Anglia. Over the fossil beds containing *Pithecanthropus* are stratified deposits forty-five feet in thickness, recalling the Mauer sands (see page 164). In terms of years, a conservative estimate would give to *Pithecanthropus* an age of 400,000 to 500,000, or in round numbers approximately half a million years.

Heidelberg Man (*Homo* (*Paleanthropus*) *heidelbergensis*)

The jaw upon which this species is based bears the unique distinction of having caused no controversy whatever among anthropologists, for the absolute perfection of the specimen, the stratigraphic position, and the circumstances of its discovery leave no ground at all for doubt or dispute. It came to its fortunate discoverer, Doctor Otto Schoetensack, as the just reward of some twenty years of patient scrutiny and expectation. It was found at Mauer in southern Germany in 1907. This little village lies in the valley of the Elsenz, a trib-

---

[4] See Lull, "Organic evolution," Macmillan, 1929, Pl. XXXI, Fig. A. McGregor's restorations, and those of Rutot, are reproduced in Osborn's "Men of the Old Stone Age," Scribner's, 1919.

[5] Gregory, W. K., The origin and evolution of human dentition etc., *Jour. Dental Research*, vol. 3, 1921, page 691, fig. 270.

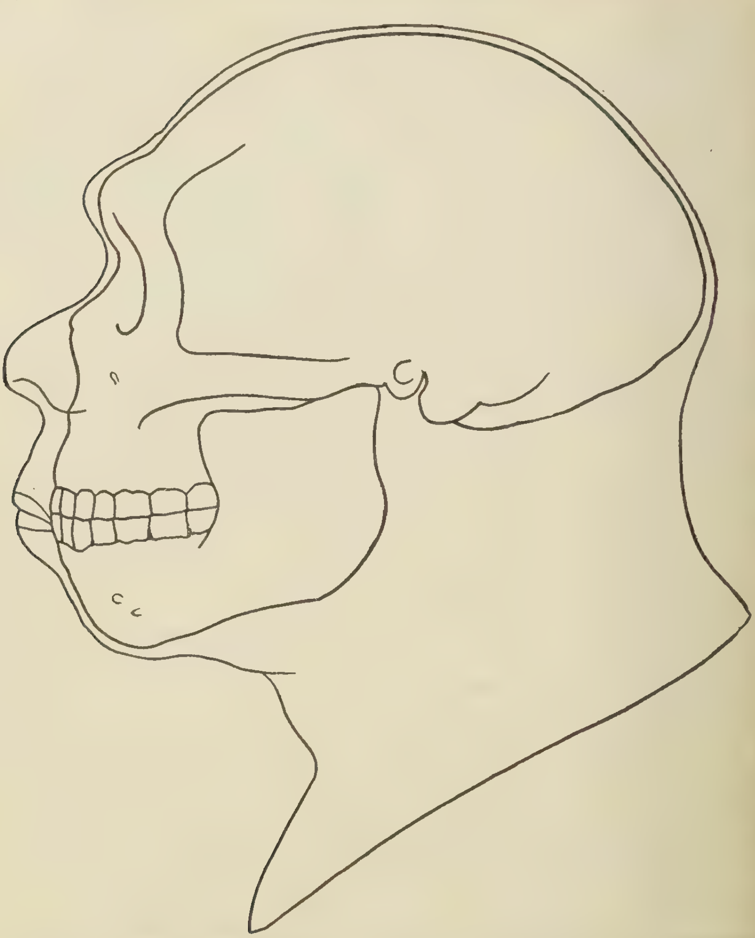


FIG. 33. *Homo heidelbergensis.* Skull and face, based upon McGregor's restoration of the skull, the lower jaw only being known. Two-fifths natural size.

utary of the more famous Neckar, and at a distance of ten kilometers southeast from the city of Heidelberg, famed for being one of the oldest seats of scientific learning in central Europe. The Mauer sands are river valley deposits, the upper portion of which is regarded by Schoetensack as upper, the rest as lower, Pleistocene. From this locality has come a fauna of mammals which compares with that of the pre-Glacial forest beds of Norfolk, England. The jaw itself was found in the lower portion, about seventy-nine feet below the summit of the deposits.

The lower jaw is complete to the last detail, although the teeth of the left side, which adhered to a limestone pebble, were broken off upon the removal of the latter. They are, however, carefully preserved, and the accident brought to light yet other characteristics not otherwise visible.

The jaw is very primitive, heavy, and massive. It lacks entirely the chin prominence so characteristic of modern man, as the front profile of the jaw slopes away as does that of a gorilla. Within the jaw at the symphysis there is the genial pit for the attachment of the tongue muscles as in the anthropoids, and, like them, the bone encroaches on the floor of the mouth. In both these respects the jaw is more simian than human but not sufficiently so to preclude the possibility of rudimentary speech. The body of the jaw is not unlike that of the successor of Heidelberg man, the Neandertal race, but the ascending branch which gave attachment for the masticating muscles differs in shape, being gibbon-like, and is much greater, as great in fact as that of a female orang. The teeth, while actually large, are relatively small, and the taurodontism is developed in a marked degree, as shown by the enlarged pulp cavity, dilated crowns, and abbreviated roots. The teeth are regularly placed, and the canines are not in any way bestial in their development, less so, indeed, than in some modern men. Without the teeth, the Heidelberg jaw might well be considered as that of an ape, but the teeth affirm its human affinities although in their development and in the form of the dental arch they are prophetic of Neandertal, not of modern, man. Keith does not believe that either Heidelberg or Neandertal man lies in the direct line of modern descent, but that the taurodont dentition implies a specialization for a rough herbivorous diet and that in this respect both races show a departure from the more simian dentition and implied feeding habits of the main line of descent into *Homo sapiens.*

While the skull of Heidelberg man is yet unknown, Doctor McGregor has nevertheless attempted its reconstruction, for of course many dimensions, as well as the character of the upper teeth, can be learned from the lower jaw, while the remainder of the skull was studied from its Neandertal successor. The result is a pre-Neandertal skull, elongated, with a low forehead, prominent brow-ridges, and a rounded dental arch, and there is reason to believe that this reconstruction will prove prophetic when the actual cranium is revealed to us by discovery, unless the latter shows certain unique and entirely unexpected features.

The probable contemporaneity of the associated fauna with that of the pre-Glacial forest beds has already been mentioned. Osborn in 1915 considered both the fauna and the jaw to pertain to the Second Interglacial time, but Schoetensack, Geikie, and others would assign them to the First Interglacial (Lower Pleistocene). Gregory says (1921, page 126):

> If of Lower Pleistocene age, the Heidelberg jaw shows that the most important diagnostic characters of the dentition of the Hominidæ had already been acquired at the beginning of the Pleistocene epoch and indicates that prehuman transitional conditions must be sought in earlier geological ages. If, on the other hand, the Heidelberg jaw dates only from the Middle Pleistocene, then transitional conditions may be looked for as late as the Lower Pleistocene or Upper Pliocene.

The age of this venerable relic read in terms of years is at least 400,000, and the associated flints are Eolithic in culture.

Recently other material has been discovered in the Mauer nd pit, part of which may pertain to *Homo heidelbergensis;* hile detailed descriptions are not as yet available, they seem bear out our conception of the brutal appearance of this ncient type.

The Dawn Man of Piltdown (*Eoanthropus dawsoni*)

This is by far the most ancient *English* human relic yet iscovered, although there is some question as to the precise ating and, owing to the fragmentary character of the ma- rial when it came into scientific hands, it has aroused a great eal of controversy, in marked contrast with the unhesitating ceptance of the jaw of Heidelberg. The specimen was ound at Piltdown, on the Ouse, Sussex, in a shallow stratum gravel, less than four feet in thickness at the point of dis- overy. This gravel rests on a bed-rock of Mesozoic age, the astings beds. From the lowest six-inch layer of the Pilt- own gravels, where everything is stained a deep brown, came e skull, together with certain crude (Eolithic) implements nd the remains of several animals, long since extinct. This t has been worked for some time for road-mending flints nd thither occasionally came Mr. Charles Dawson, a local wyer and antiquarian, to secure the flint implements which om time to time came to light. One day a workman gave r. Dawson a fragment of the skull parietal. This started a ng search, ultimately resulting in the finding of other char- cteristic portions of the cranium, a ramus of the jaw with veral molars *in situ,* a canine tooth, and two nasal bones. hese fragments, which represented what was at first an entire ull unwittingly shattered by a workman's pick, were sub- itted to Sir Arthur Smith Woodward of the British Museum, ho began the laborious process of reconstruction of a com- lete skull from the several isolated pieces. It is but natural at among the several workers who essayed the same task, Smith Woodward, Keith, and McGregor, there should be some difference of opinion, which is manifest principally in a little variation as to the estimate of skull capacity. But in the main there is agreement as to the general form. The cranium is extremely thick-walled, averaging four-tenths of an inch, with a rather steep, though contracted and ape-like forehead, and one that lacks the prominent brow-ridges of Neandertal man. The skull was nicely balanced on the neck as in ourselves, implying an erect posture in further contrast to the men of Neandertal. The brain-cast was submitted to the high authority of Professor Elliot Smith, who pronounced it the "most primitive and most simian human brain thus far recorded."

The jaw has proved to be a veritable bone of contention. Everything pointed to community of origin with the cranium, except its remarkably primitive character. One American authority, G. S. Miller, Jr., who studied, not the original but a cast, came to the conclusion that the jaw and skull could not possibly pertain to the same individual or even the same genus, but that the former was that of a fossil chimpanzee, to which the technical name of *Pan vetus* was given, despite the fact that fossil anthropoids were heretofore unknown in England. In this conclusion Mr. Miller has had quite a large American following. The matter has, however, been settled beyond question by the finding of a second specimen of the Piltdown man some two miles distant, consisting of diagnostic cranial fragments associated again with a lower molar of precisely similar character to those in the first jaw, a happening which could hardly occur, according to the law of probabilities, in both of the only known instances if the jaw and skull were not those of the same form.

The jaw is indeed peculiar, as the symphysis is distinctly simian, while according to Keith, the rear part is as distinctly human. The whole, taken together with the canine tooth,

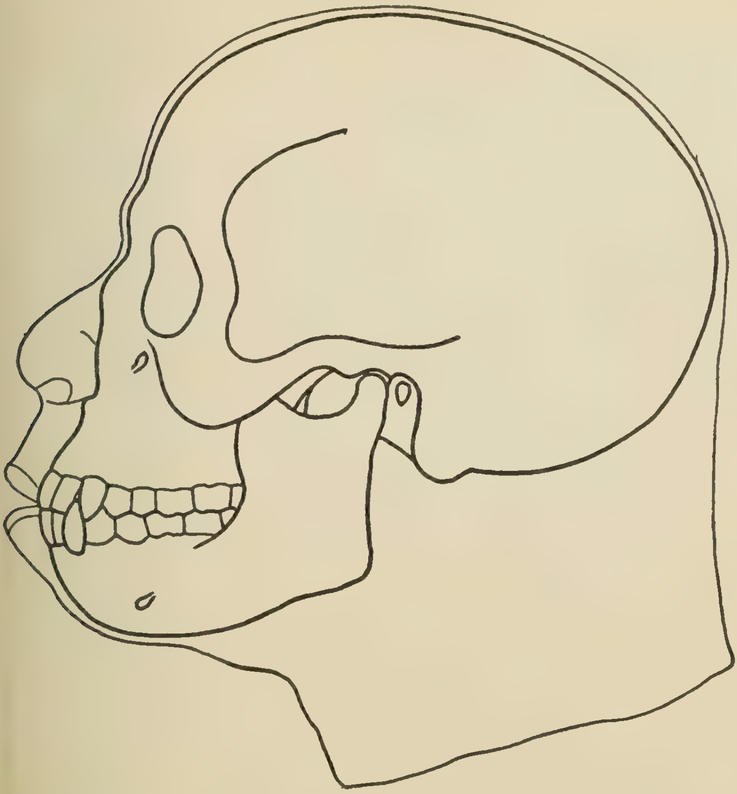


Fig. 34. SKULL AND FACE OF PILTDOWN MAN
Eoanthropus dawsoni.
Two-fifths natural size. Adapted from McGregor.

oints to a man of bestial visage, united with a rather modern-
ooking cranium, a combination which excludes him from our
pecies and genus, and to which the name *Eoanthropus daw-
oni* is most aptly applied, no one, as Keith says, having ever
nticipated the discovery of one of man's progenitors showing
uch a remarkable mixture of human and simian characters.
Chief among the peculiarities of the jaw is, therefore, the

symphysis, which is even more simian than that of Heidelberg in that there is no rudiment or suggestion of the forming chin. The ape-like genial pit is present, together with the encroachment of bone on the floor of the mouth. The anterior teeth, so far as known, are also simian, while the molars are human, although, as Gregory says, extremely like those of a chimpanzee, but these, in turn, are closely related in pattern to primitive human molars.

As has been said, very primitive eoliths, stained brown, were found actually associated with the skull; in the gravel above, however, the flints are a brilliant colored iron red and of such degree of workmanship that Dawson considers them as Chellean or at the earliest pre-Chellean in age. The man, however, as has been said, was not buried down into the older strata but contemporaneous therewith, possibly the result of a drowning accident. Certain British authorities refer the older gravels to the Pliocene, but the more widely accepted belief is that the Piltdown man is Lower Pleistocene, of First or Second Interglacial time, so that in terms of years his age is, speaking conservatively, from 300,000 to 400,000 years.

These remains occurred so near the present land surface that had they not shown evidence of great structural antiquity, their authenticity would be greatly in doubt. As it is, they are conceded to be ancient, the chief discussion being as to how ancient and whether or not the jaw pertained, whether the canine tooth was upper or lower, and finally as to the cubic contents of the skull. (See Plate VI, page 160 and Fig. 34.)

Neandertal or Mousterian man (*Homo neandertalensis*)

This is now a well-established race with considerable range of variation within it, for of it there have been found relatively numerous individuals of greater or less degree of perfection. Of these, the first in chronological order, and the nost ancient in point of time, is the Gibraltar skull discovered n 1848, but unappreciated scientifically for so many years that ts position in the series has been subordinate instead of at the ead. It is now preserved in the Museum of the Royal Colege of Surgeons.

The most famous skeleton, which gave its name to the ace, is that found at the mouth of a cave in the Neandertal orge of the valley of the Düssel, a German tributary of the hine. While apparently nearly perfect at the time of disovery, but little of the skeleton is now preserved in the Proincial Museum at Bonn. A skull-cap, ribs, part of a right capula, clavicle, humeri, ulnæ, femora, right radius, tibia, and portion of the left pelvic bone are the chief parts remaining, nd, as might well be supposed, the publication of the find ave rise to much contention as to whether it represented a ype of man or was merely the relic of some poor waif of umanity, diseased or otherwise, the result of abnormal rowth. It was not until the further discovery of two other dividuals at Spy in Belgium in 1886, which again bore the istinguishing features of Neandertal man, that it was fully onceded that they represented a race, and that the characterstics which they exhibited were diagnostic. Later finds, hough not in chronological order, have been made at the ollowing places: Le Moustier, La Chapelle-aux-Saints, La errassie, La Quina, and Pech de l'Azé, France; Bañolas, pain; La Naulette in the Lesse Valley, Belgium; Ehringsorf near Weimar, Germany; Krapina, Austria; and at Tierias on the Sea of Galilee in Palestine.

The anatomical features of the Neandertal race are now ell-established, largely through the very detailed studies of rofessor Marcelin Boule on the material from La Chapelle-ux-Saints in the Paris Museum. *Homo neandertalensis* was f low stature, hardly exceeding five feet three inches for the nales and less for the females. The posture was not fully

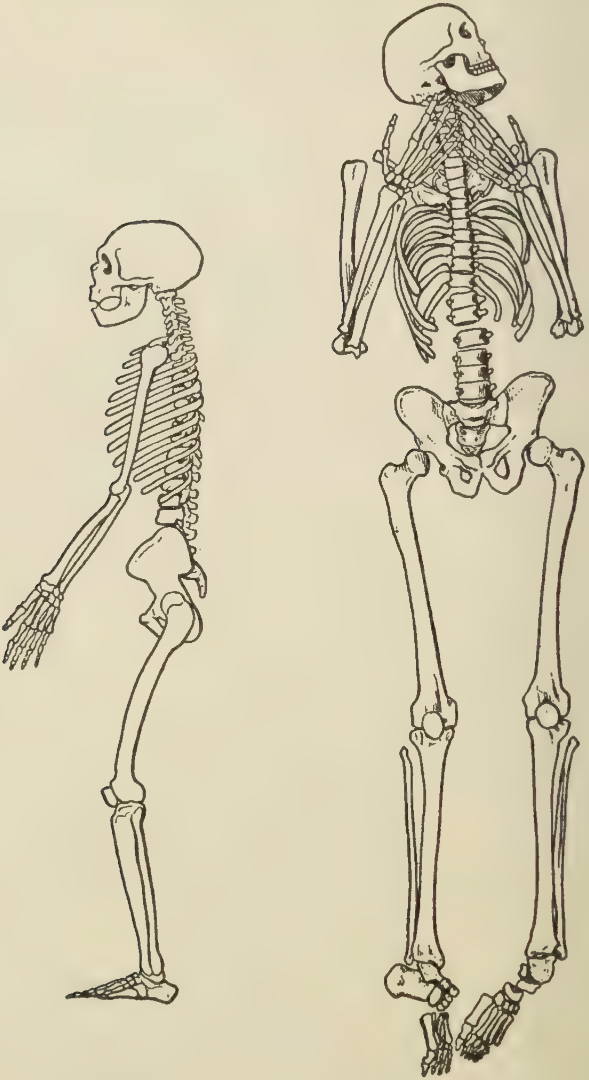


Fig. 35. SKELETON OF NEANDERTAL MAN (LEFT) COMPARED WITH THAT OF CRÔ-MAGNON MAN
From Lull, after Boule and Verneau.

erect,[6] as shown by the curved thigh bones, slighter cervical flexure of the spine, and the position of the foramen magnum of the skull. The head was borne on the immensely muscular neck in such a way that the face was thrust forward in an ape-like manner, thus lacking the delicate poise which it would possess were the carriage more fully erect.

The skeleton of Neandertal man is peculiar, not alone in the slight cervical flexure of the vertebral column and in the presence of curvature in the thigh, but in the enlarged articulation of the limbs, with knee and hip joints somewhat bent, and n the peculiarly rounded ribs, all of which point to a clumsy, shuffling, loose-jointed being of great muscular power. The distal segments of the limbs are relatively short, in marked contrast with those of the great man of Crô-Magnon described below.

The skull of Neandertal man is very large, with a cranial capacity of 1,600 c.c. (La Chapelle) as against an average modern cubic content of about 1,400 c.c. The skull is long, as are all prehistoric crania, but the vault is low and the hinder part curiously depressed and broadened out, "bun-shaped," as Keith expresses it, which, together with the great apparent musculature of the neck, must have increased the peculiarity of his appearance. Anteriorly, the supra-orbital ridges or tori are greatly developed and are confluent across the forehead, not divided into two parts by a median depression as with modern man. The nasal profile is concave and the upper jaw very deep, indicating a long upper lip. The lower jaw is not unlike that of Heidelberg, nevertheless it shows a distinct advance over the latter in that, while the chin prominence is yet lacking, there is indication that dental reduction, already n evidence, is beginning to cause a recession of the tooth-line

---

[6] Careful studies of the specimens by Doctor McGregor, as yet unpublished, seem to indicate that the posture of Neandertal man was probably no less erect than that of some slouching modern types.

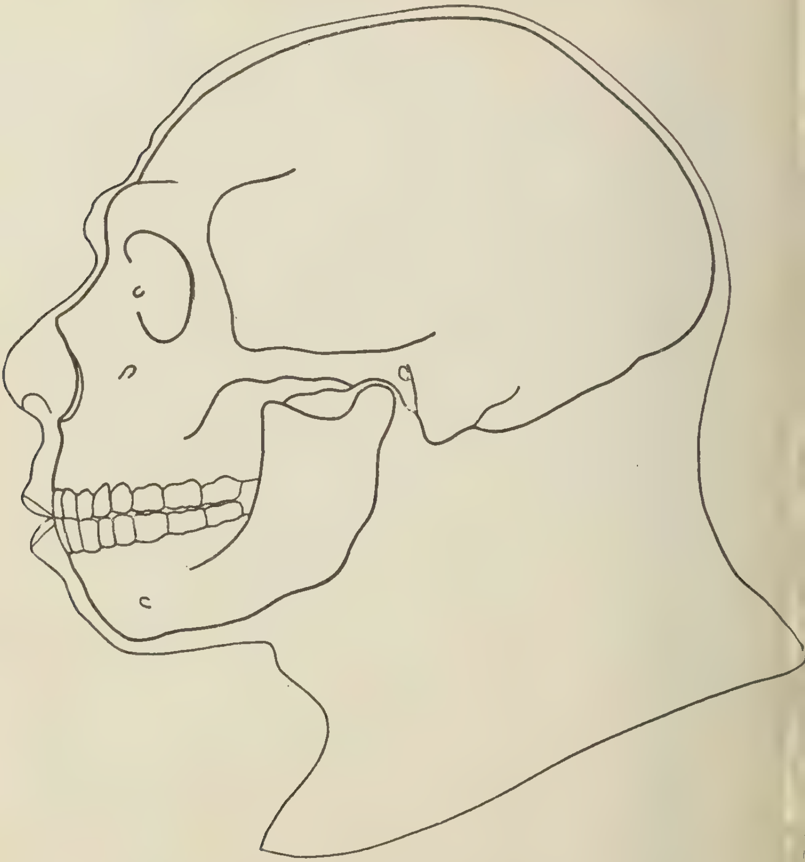
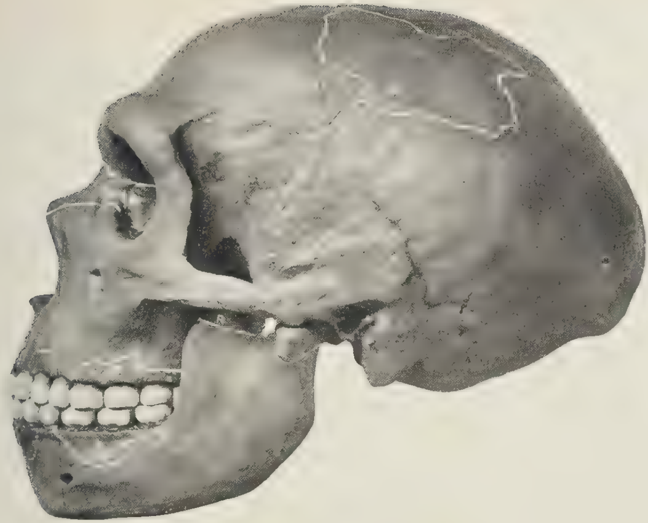


FIG. 36. SKULL AND FACE OF NEANDERTAL MAN
Homo (Paleanthropus) neandertalensis.
Two-fifths natural size. Adapted from McGregor and Boule.

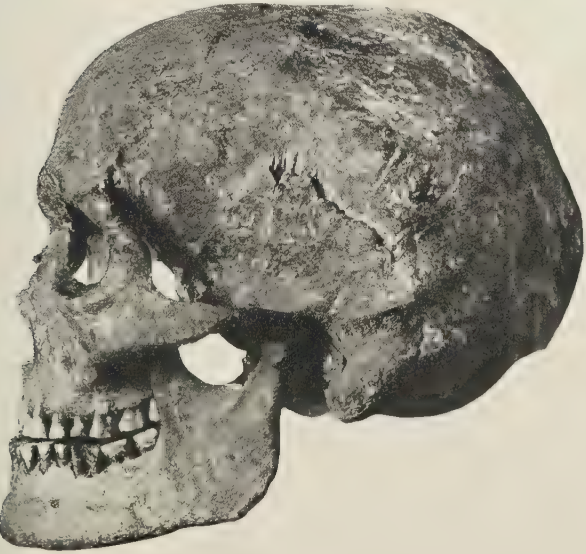
to a position more nearly above the chin, giving the latter a greater relief. (See Plate VI, page 160; Plate VII, page 174; and Fig. 36.)

The teeth are of the taurodont character defined above, large of pulp capacity and short of root, again an adaptation



A. SKULL OF NEANDERTAL MAN

From La Chapelle-aux-Saints. Restored by McGregor.
R, portion restored.



B. SKULL OF CRÔ-MAGNON MAN

From Grotte des Enfants. After Verneau.

PLATE VII.—Reproduced by courtesy of Doctors J. H. McGregor and W. K. Gregory, of the American Museum of Natural History.

according to Keith, to a coarse vegetative diet. In teeth and palate form, Neandertal man shows a greater degree of specialization than does our own race although in other respects more primitive.

The brain of this man was not as yet sufficiently advanced to learn to substitute other and more effective devices for various needs, so that the jaws still had varied uses in contrast with their very restricted function to-day.

The brain itself shows a certain specialization in its size, but the relative development of those parts wherein lay the higher mental functions was not great. Nevertheless, Neandertal man was a skilled worker in flints, had harnessed fire, and by the reverential burial of his dead surrounded by beautifully wrought objects whose surrender implied a very real sacrifice on the part of the survivors, together with apparent food, had in greatest probability a belief of some sort in immortality.

It is in the form of the cranial cavity and of the supraorbital ridges that the Neandertal skull departs most widely from that of modern man, and it is in these two points that the resemblance with the anthropoids is most pronounced. They are both, however, in part at least, explicable as a response to great muscular development of neck and jaw. As Keith says of him, certain peculiarities of his were distinctly simian, but not all of them, as he possessed other traits distinctly his own.

The following ideas have been advanced concerning the status of this interesting race: that he was the product of disease; that he was ancestral to modern man, representing the Pleistocene stage in human evolution; that he was merely an extreme variant of modern man himself, who had retained an unusual share of ape-like traits. The present opinion, however, looks upon him as "a separate and peculiar species of man which died out during or soon after the Mousterian period" (Keith).

Modern representatives of Neandertal man. As a race, *Homo neandertalensis* is surely extinct. Whether or not his blood has entirely vanished from the earth is not known, for in diverse people, as, for instance, a certain Holland strain, the so-called Old Black breed of the Shetland Islands, and again in the west of Ireland, we find certain Neandertal characters still prevalent, but not all of them. The same thing is also true of the Australian natives, whose physiognomy is often very suggestive of the Neandertals, so much so that they have been held by certain authors to be persistent representatives of that race. But while many individuals show one or more of the distinctive characters, no one individual ever possesses all.

Rhodesian Man (*Homo rhodesiensis*)

The exact place of the interesting relic from Broken Hill mine, northern Rhodesia (see page 159), is yet to be established, both from the standpoint of antiquity and the position that it holds in its human relationship. The preserved remains, probably complete when found by the workmen, consist of a skull with a part of the lower jaw, both so perfect that no questionable reconstruction of either cranium or facial bones need be made. Certain other skeletal elements are also present, such as the tibia and both ends of the femur, the collar bone, part of the scapula and of the pelvis. Part of the upper jaw of a second individual was found, thus establishing the existence of a race or tribe as against an aberrant individual.

The facial region shows a very primitive character, with brutal, forwardly projecting jaws. The brows are immensely prominent, so much so that they dwarf the forehead above and emphasize its flattened look. The nose was broad and flattened but human, and the palate so broad and rounded that it is less ape-like than in the modern negro. The lower jaw

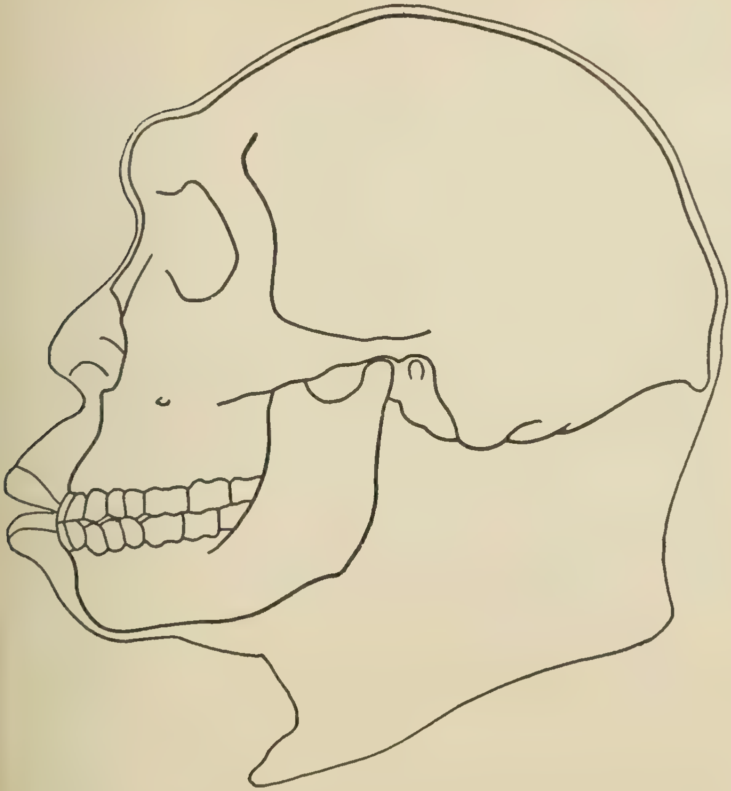


FIG. 37. SKULL AND FACE OF RHODESIAN MAN
Homo rhodesiensis.
Two-fifths natural size. Adapted in part from Woodward.

must have been of enormous strength and size to offset it. Smith Woodward tried the Heidelberg jaw on the skull but found it too short and narrow. The Piltdown jaw, on the other hand, he found too long, and to be further excluded from comparison by the prominent canines which in the Rhodesian man are not distinctively developed. The teeth as a whole are strongly rooted, although badly worn, and subjected to caries, a disease never before observed in a prehistoric skull. The third molar or wisdom tooth is undergoing reduction as in modern man.

If one may judge from the position of the foramen magnum, the straight shin, and the character of the ends of the thigh bone, the posture was apparently erect.

As one views the Rhodesian skull, he is certainly strongly impressed with its Neandertal-like appearance, but this applies largely to the face, for the laterally compressed instead of depressed cranium is a departure in the more modern direction. It would seem as though close relationship is indicated between the two, although in some respects Rhodesian man is more advanced. Certain community of food adaptation or use of the jaw instead of other means in accomplishing necessary work, may account for the facial similarities which in the Rhodesian man, as in that of Piltdown, may well have lagged behind the evolution of the rest of the skull.

Culturally, Rhodesian man must have been very primitive, for the only associated implements are certain rounded pieces of limestone of doubtful utility, although the crushed skull of a lion-like creature found in association is indicative of a certain defensive value.

The dating of Rhodesian man is difficult. The skull is fossilized, but the associated animals are all recent, so that the latter criterion of age fails us in attempting to fix other than late Pleistocene for the time when this man lived. The position of the remains in a cavern is not so trustworthy as usual, for while buried under tons of mineralized bones, they may well have been intruded by means of a shaft-like cave. Bather thinks that, whatever the age of the associated animals, the skull is appreciably older. The African fauna has a distinct Pleistocene facies as compared with that of Asia. Rhodesian man is therefore probably Pleistocene, though where he should be placed in the European chronology is not evident.

Homo sapiens

Upper Paleolithic man. The most notable of the several races of our own species found in prehistoric Europe is that of Crô-Magnon, in almost all respects the most perfect man physically that has come within our knowledge. The first record of the existence of this race was found at Gower, Wales. Later seventeen skeletons were discovered at Aurignac, France, in 1852, but were lost to science through subsequent burial in the village cemetery. In 1868 others were discovered at Crô-Magnon, and these may yet be seen in the great Museum of the Jardin des Plantes in Paris. In all there were five skeletons, an old man, a woman, a child, and two young men, and these specimens are now looked upon as the types of the race.

The most impressive thing about Crô-Magnon man is the majestic height, which averages six feet one and five-tenths nches in the young men, while the man from Mentone, shown n Fig. 35, was six feet four and five-tenths inches. The women, on the other hand, had an average height of only five feet five inches, but little above that of to-day. The limb proportions and the great chest are suggestive of negroes, but not the skull, which is decidedly more Asiatic than African in implied affinities.

The skull is very large, even the female brain exceeding that of the average modern male. This is perhaps the more significant, since, as Keith says, the size of the body has a direct influence on the size of the brain. The Crô-Magnon skull, while long and narrow, is entirely modern, lacking as it does the great brow-ridges of his predecessors. Nor is the brain in any way distinctive from that of existing man. The face, on the other hand, is broad, especially across the cheek bones, giving a disharmony of face and cranium. The facial

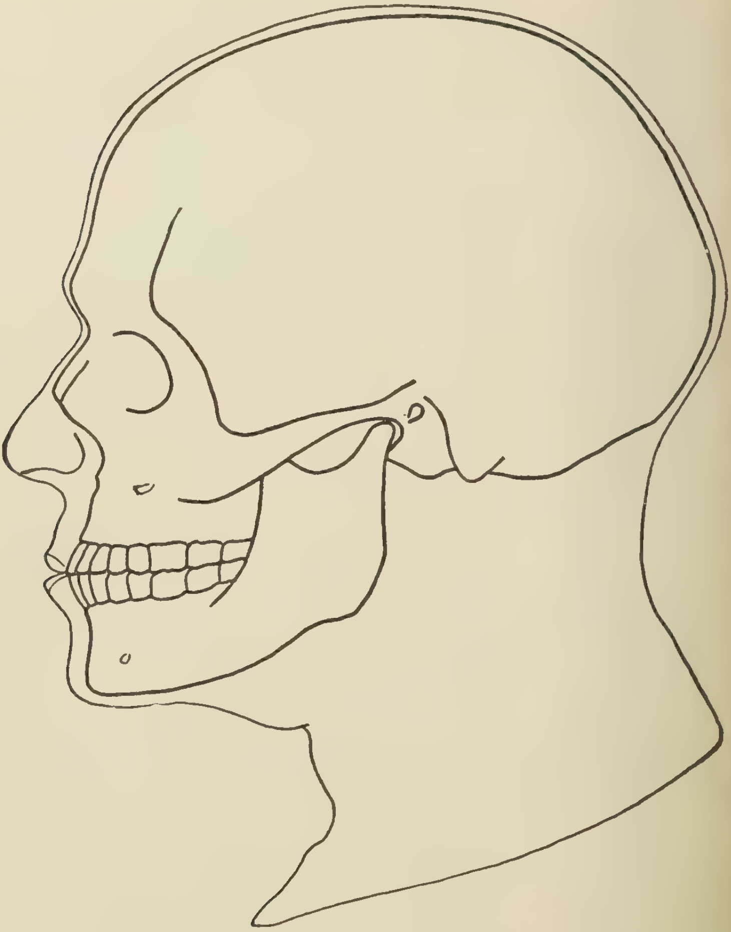


Fig. 38. SKULL AND FACE OF CRÔ-MAGNON MAN
Homo sapiens.
Two-fifths natural size. Adapted in part from McGregor.

angle is equal to that of the highest modern man. (See Plate VI, page 160; Plate VII, page 174; and Fig. 38.)

The jaw is strong and the chin, though prominent, is narrow when seen from in front. The palate is also narrow and the dental arch and teeth are of a relatively high type.

In Obercassel, near Bonn, Germany, there is an extinct race resembling very closely the Crô-Magnons except for a short stature.

Culturally, these late Paleolithic men stood very high, not only in their production of flint implements of Aurignacian type (see table, page 151), but because it was in representatives of this race that primitive art found so very remarkable an expression. This art—sculpture, engraving, and painting—has been found in great abundance in and upon the walls of caverns in the Dordogne region and in the Bas Pyrenees, and on the northern coast of Spain. A detailed description of it s beyond the scope of this essay, and the reader is referred to the elaborately illustrated works by l'Abbé Breuil,[7] Osborn,[8] MacCurdy,[9] and others. The significance of this work, whether religious or merely a manifestation of an artistic impulse, is not at all clear. That the great bulk of the representations were of animals has perhaps some bearing on the question; at all events, they give us an insight into the psychic development of a race 25,000 years ago fully in accord with their magnificent physique. (See Chapter IX.)

Among other types of *Homo sapiens,* more or less contemporaneous with Crô-Magnon man, is that of Grimaldi, of which the typical skeletons come from the famous Grotte des Enfants near Mentone in southern France. The individuals, a woman and a boy, were apparently laid on the floor of the cavern and protected by stone blocks over which in the subsequently accumulated cave earth there was buried a typical Crô-Magnon man. The Grimaldi individuals show several features which have been interpreted as negroid,—long narrow crania, flattened nose with typical nasal gutters at the base, protruding teeth and slightly retreating chin, and palate and teeth like those of the Australians. Although the lower limbs are disproportionately long, the stature was low.

---

[7] References to the works of Breuil may be found in the bibliography of Osborn's "Men of the Old Stone Age."

[8] H. F. Osborn, "Men of the Old Stone Age," 3d ed., 1919, Scribner's.

[9] G. G. MacCurdy, "Human Origins," 2 vols., 1924, D. Appleton and Company.

Sollas makes much of this occurrence, together with the finding of steatopygous figurines in adjacent Mentone caverns suggestive in their conformation of characteristic bodily curvatures of the modern Bushmen. He therefore, on these and other data, concludes that "Mentone was inhabited at the beginning of the Aurignacian age by a race allied to the Bushmen." One is very loath, however much the resemblances may point to it, to attribute the glories of Aurignacian art to a negroid race, in the presence of the splendid Crô-Magnons. The Grimaldi men may have been representatives of a wave of invasion from northern Africa which spread for a while into Europe, to retreat once more before the advance of the more vigorous Asiatics. The Crô-Magnon race has also ceased to exist as such, although in the Dordogne region, within the limits of their ancient home, there dwell individuals which possess many of the physical traits of their probable Aurignacian ancestors. We have to go to Asia to the region north and south of the Himalayas to find peoples whose facial characteristics best resemble those of Crô-Magnon man, while the stature and bodily build are best displayed in the Sikhs.

The decline of the Crô-Magnons, Osborn says (1916, page 450),

> may have been due partly to environmental causes and the abandonment of their vigorous nomadic mode of life, or it may be that they had reached the end of a long cycle of psychic development. . . . We know as a parallel that in the history of many civilized races a period of great artistic and industrial development may be followed by a period of stagnation and decline without any apparent environmental causes.

There are yet a number of remains pertaining apparently to *Homo sapiens.* These are the Galley Hill skull in the Thames gravels, and the remains from Dartford, Clichy, Moulin Quignon, Grenelle, Denise, Olmo, and Castenedolo. All of these have been in dispute as to their antiquity, principally because of their very modern character. But Keith groups them collectively under the head of pre-Mousterian man, accepting Galley Hill, Clichy, and Olmo as certainties, and believes that they may well be cited to prove the great antiquity of our own species. Other competent authorities, however, consider the above cited as "impossible and not proven." Keith's contention is that *Homo sapiens* appeared at a remote time, flourished for a while, and disappeared, to be replaced by the more primitive but not ancestral Neandertal man of Mousterian time. This last was in turn deposed from human dominance and replaced by the higher race again in the character of Crô-Magnon man. He feels, therefore, that the divergence of the primitive stock into the Neandertal, Piltdown, and *sapiens* stems occurred early in the Pliocene, and that the differentiation of *H. sapiens* himself into the four great ethnic groups, African, Australian, Mongolian, and European, occurred before the beginning of the Pleistocene. On this account he is perfectly able to accept a Pleistocene age at least for the men of the New World. Back of the Heidelberg man, the European record is blank, unless indeed Piltdown and Castenedolo be older. The last particularly Keith doubts.

Tertiary man. Professor Osborn in *Natural History* describes at some length beliefs which he holds as the result of a visit to East Anglia in 1921. That visit led to a very firm conviction of the presence of Upper Pliocene or Tertiary man n England, as shown by his cultures. These are three, two of which (1) the pre-Crag industry (rostro-carinate flints) of Ipswich, and (2) the Foxhall flints of Ipswich, are placed in the Upper Pliocene, while (3) the giant flints of Cromer are considered of Lower Pleistocene age.

Supposedly associated with the Foxhall flints was found a human jaw which unfortunately cannot now be located. If it could be found and the certainty of association determined, it would far antedate both that of Piltdown and of Heidelberg. The figure which Osborn published of this jaw, from the original by Collyer in 1867, is remarkable in that it is the jaw of *H. sapiens,* if correctly drawn, and not primitive at all! But this is exactly what Keith's arguments would lead us to expect. With the apparent insufficiency of evidence, however, judgment as to the antiquity of our own species should be for the present withheld.

SUMMARY

The recorded physical changes in prehistoric man are:

Increasing cranial capacity, with perfection of the brain, especially in that portion which is concerned with the higher intellectual faculties and with speech.

Change in skull conformation, heightening forehead, and lessening brow-ridges.

Reduction of jaw power and of dental arch, which results in the formation of the chin prominence.

Changes in the teeth, such as reduction of canines and loss of diastemata.

Stature increasing and becoming more erect, although the earliest known hominid, *Pithecanthropus,* was fully upright, pointing to great antiquity for this characteristic.

As yet there is no actual connection with ape-like forms such as *Dryopithecus,* which may be ancestral to both the modern apes and man, but the table here reproduced (Fig. 39) gives a tentative view of implied relationships. Exploration in Asia now being carried forward under the auspices of the American Museum of Natural History will, it is hoped, yield

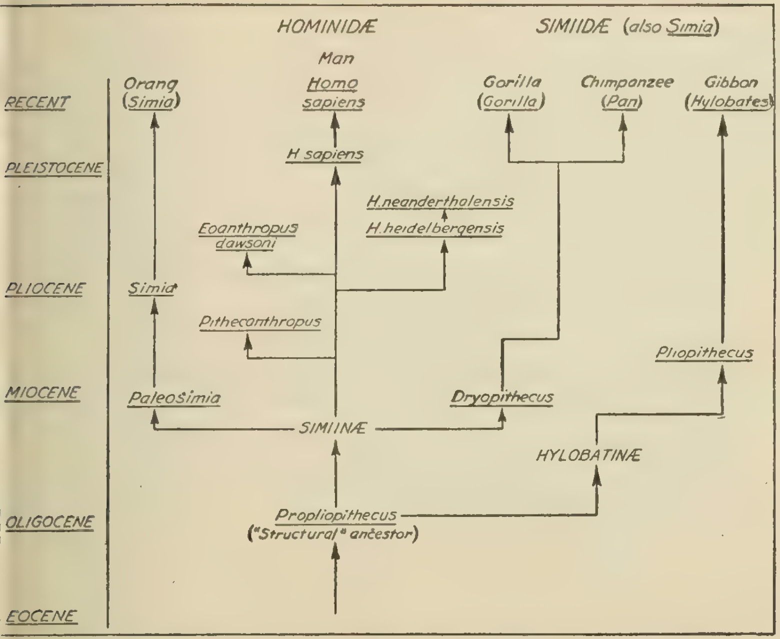


FIG. 39. PROVISIONAL PHYLOGENY OF MAN AND THE ANTHROPOIDS
Modified from W. K. Gregory 1920 (1916).

additional light on the problem of human origins, for all of our evidence points to central Asia as the birthplace of mankind, and to the Miocene, 1,000,000 to 2,000,000 years ago, as the time of his origin.

The discoveries at Chow Kou Tien, near Peking, China, of two teeth in 1921 and very recently jaws and several skulls, as yet undescribed, but representing a very primitive type, may aid greatly in the solution of this problem.

The antiquity of man has thus been made known by *direct* evidence in the form of human relics, the greatest age of which can hardly be less than half a million years. *Corroborative* evidence lies in the great variation, not alone between the several species of prehistoric man, but also among the many races of *Homo sapiens* himself, of which Gregory recognizes twenty-six, with a number of sub-races. And that the major divisions are very old is attested by ancient murals and other documents of the Egyptians and other oriental peoples.

Man's distribution is world-wide. In these days of easy travel, this is not so significant as it was in the ancient days when dispersal meant slow tribal migrations sometimes covering generations of time.

The intelligence of man so far surpasses that of his nearest competitors, the anthropoids, that the mental gulf between them is immeasurable, while the moral and spiritual attributes of mankind were also long in the making.

Communal life, as contrasted with the much more common herding instinct of the gregarious, has been attained but twice, among the social insects and among men. A long period of time is again necessary for this attainment.

Finally, man's remains or the products of his industry are found associated with numerous extinct creatures, of which he alone survives.

CHAPTER VI

THE NATURAL HISTORY OF MAN

HARRY BURR FERRIS
E. K. HUNT PROFESSOR OF ANATOMY, YALE UNIVERSITY

The fundamental structural unit in man and other organsms is a microscopic mass, called a cell, which varies considerbly in shape and size, and possesses a central spherical body, ermed the nucleus. Animals composed of a single cell are alled protozoa, those made of many cells, metazoa. Man is metazoan and it has been estimated that his body is comosed of more than twenty-six trillion cells. Animals without longitudinal, dorsal body axis are called invertebrates while hose with such an axis are known as vertebrates. Man has uch an axis and also possesses other characters common to he vertebrates, such as a bony cavity, dorsal to the body axis, or the hollow central nervous system, and also an internal, egmented skeleton as shown in the serial repetition of ribs nd vertebræ. Man is also a mammal in that he possesses nammary glands and hair and has the thoracic cavity, containng the heart and lungs, separated from the abdominal cavity y a complete diaphragm. Because of structural similarities e belongs to the order of primates together with the lemurs, nonkeys, and apes.

Structurally man differs from his nearest relatives, the anhropoid apes, by differences of degree rather than of kind uch as the better adaptation of his feet and vertebral column o the upright position, the non-opposability of the great toe, the greater size of the cranium and the brain, the relatively smaller and less projecting face, and the relatively and absolutely longer lower extremities. Man does not differ much more from the tailless apes, like the gorilla, than they differ from the old-world tailed apes.

Anthropologists generally agree that living man is represented by one genus *Homo* and a single species *sapiens,* and that the various races are merely varieties of *Homo sapiens.* Fossil remains of man have been found, as has been explained in a previous chapter, which represent several other species and which show marked ape-like characters. It is not certainly known whether present man has evolved through these fossil forms or whether they rather represent collateral lines now extinct.

The races differ notably in many parts of their bodies. The most important differences are shown in the size and form of the head, in the skeletal and physiognomic characters, in the color of the skin, the form and color of the hair, and the body proportions. There are also differences in the susceptibility to disease and, although less marked, psychic differences in the races, particularly as exhibited in the temperament. The soft tissues likewise show racial differences although little in regard to them is known. This subject offers a large field for further investigation. It is possible also that the races differ in protein reactions and hormones, as held by some authorities, a subject as yet quite unexplored.

Blumenbach's classification of the races is as satisfactory as any, although the use of a single criterion of race distinction, namely, skin color, is open to objection. Blumenbach classifies the races as follows: (1) Caucasian, having a white skin, (2) Mongolian, having an olive skin, (3) Ethiopian, having a black skin, (4) American, having a dark skin with more or less of a red tint, and (5) Malay, having a brown or tawny skin. Some classifications include the Australians as a

eparate race. Additional interest is given to this classification
f the races as it corresponds in a general way to their geo-
raphic distribution as shown in Fig. 31.

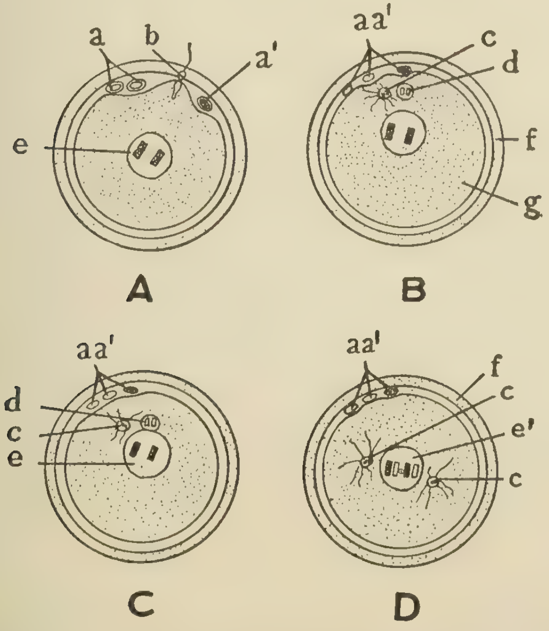


FIG. 40. DIAGRAM SHOWING THE FERTILIZATION OF THE OVUM
A, the mature ovum with a central nucleus, or, as it is termed, female pro-
ucleus (e), containing the reduced number of chromosomes; the others have
een given off into the first and second polar bodies (a a′). A single sperm (b) is
ntering the ovum. B, later stage in which the male pronucleus (d), with the
wo paternal chromosomes, has formed from the sperm. The sperm also brings
the ovum the centrosome (c), which is regarded as the dynamic division center.
, still later stage in which the male and female pronuclei are uniting to form, in
age D, the segmentation nucleus (e′), which contains an equal amount of ma-
rnal and paternal chromatin. Following this the fertilized egg cell will divide
y the complicated process of mitosis which insures the equal division of the
romatin material among the daughter cells. a, first polar body (divided into
wo parts); a′, second polar body; b, sperm entering the ovum; c, centrosome
later divides); d, male pronucleus; f, cell wall; g, body of cell.

Redrawn from Cunningham, *Anatomy*.

Early Prenatal Development

Reproduction is started by the union of the germinal cell of the two sexes (Fig. 40). These cells are differentiated i development before the sixth week of prenatal life and se aside in special organs, the gonads, for the perpetuation o the race. Even at this early period the sex of the germina cells of the embryo is structurally indicated. The female cell or ovum, is spheroidal in shape and although it is one of th largest cells of the body yet it is so small as to be hardl visible to the naked eye. The male cell, or sperm, is ver much smaller even than the ovum and is elongated an specialized for active motility. Both the sperm cells and th ova during their development go through a series of change which result in the reduction to one half of the chromati material contained in the nucleus. This is an important fac as the chromatin is regarded as the carrier of the hereditar qualities, and the fusion of these two cells at the time of fertilization, each with one half the normal amount of chromatin produces again a complete cell with the typical amount o chromatin and having an equal proportion of maternal an paternal hereditary substance. As a result of fertilization th egg cell has the power of almost indefinite multiplication an the still more marvelous power of differentiation so that it descendants are not all alike, but some form nerve cells, other gland cells, still others muscle cells, et cetera. This differentiation in structure is accompanied also by a corresponding functional differentiation. It may be possible to explain many o the processes of life on the mechanistic, or physico-chemica basis, but it is difficult at present to explain reproduction o this theory.

After fertilization, the repeated multiplication of the eg cell quickly produces a solid spherical mass of similar cells still almost microscopic in size, called the morula. Some of th cells soon become massed on one side and in this region tw

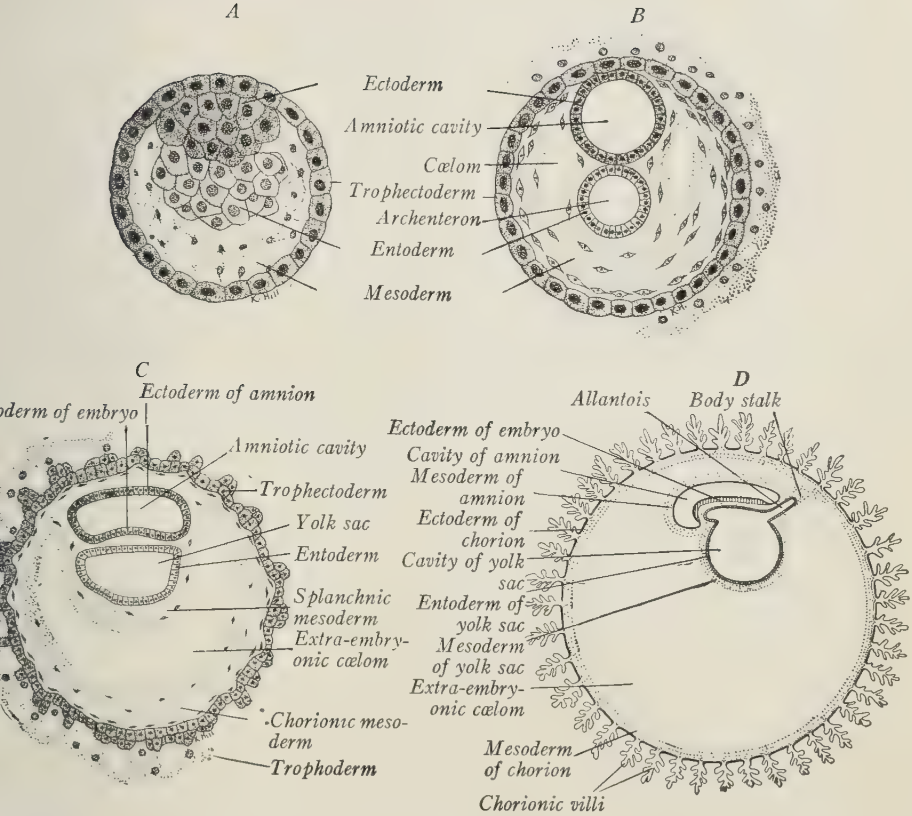


FIG. 41. DIAGRAMS OF EARLY HUMAN EMBRYOS

(Based on figures of Robinson and Minot.)

A. Hypothetical Stage.
B. Bryce-Teacher Embryo (modified).
C. Peter's Embryo.
D. Graf Spee's Embryo.

From Prentiss and Arey, *Embryology*.

By permission of W. B. Saunders & Co.

vities develop (Fig. 41), one becomes the amniotic cavity nd ultimately surrounds the embryo, and the other forms the olk sac, part of which eventually becomes the alimentary nal. Some of the cells of the two sacs, which lie adjacent nd are destined to develop the embryo, form two layers, nown as the ectoderm and endoderm, or the external and ternal membranes. This structural arrangement represents e earliest stage known in man's development, the previous ages described above being hypothetical and based on obser-ations made on the developing eggs of other mammals. ater, through the multiplication of the ectoderm cells an longated area, known as the primitive streak, is formed which dicates the anteroposterior axis of the embryo.

Along this primitive streak, between the outer ectoderm and e inner endoderm layers, a third layer is produced, known s the mesoderm. We now have in the region where the em-ryo is developing, known as the embryonic area, three yers of cells, each having its own distinctive characteristics. hese are known as the primary germ layers, and from them l the organs and parts of the body are later derived. In the uman embryo all of the organs are formed by the third month f development. From the outer layer, or ectoderm, are ormed the outer layer of the skin, or epidermis, including its arious appendages such as the hair and sweat glands, the cells ning the mouth, the enamel of the teeth, and the entire ervous system including the sensory portions of the sense rgans. From the middle layer, or mesoderm, are formed the eleton and other supporting tissues and the muscles, the ascular system, and the sex cells. From the innermost layer, r endoderm, are developed the cells lining the alimentary nal and the essential secreting cells of the various organs hich develop as outgrowths from it, such as the thyroid land in the neck, the lungs, the liver, and the pancreas. In eneral it may be said that the endoderm supplies the ali-

mentary system; the mesoderm, the locomotor apparatus, an
the sex cells for the preservation of the race; and the ect
derm, the nervous system which is placed in control of th
body and puts man in touch with his environment. Th
method of development is essentially similar in other animal

Up to this point the embryo appears as a rather simp
multicellular animal of the invertebrate type. The first ind
cation that it is to become a vertebrate is the development
a dorsal, longitudinal, rod-like axis, called the notochor
which eventually extends posteriorly from the base of t
brain through the length of the body. In the lowest forms
aquatic vertebrates this is the only longitudinal supporti
axis the body ever possesses, but in the higher fishes and t
terrestrial vertebrates, where a more stable axis is necessar
the notochord is replaced by a more rigid, segmented, bo
structure, the vertebral column.

The rudiment of the nervous system now appears, anteri
to the primitive streak and dorsal to the notochord, as a lon
tudinal groove, known as the neural groove (Fig. 42), on t
dorsal surface of the thickened ectoderm. The lateral edg
of the groove become elevated and meet and fuse above
in the mid-dorsal line thus forming a hollow, ectodermal tu
called the neural tube. Practically the entire nervous system
developed from the cellular walls of this structure. Short
afterwards a part of the yolk sac lying under the embryo
folded off, and this process results eventually in the formati
of an endodermal tube under the notochord, which is the ru
ment of the alimentary canal (Fig. 41 D).

The mesoderm, which at this stage is to be found lyi
along each side of the neural canal, becomes cleft transverse
beginning just behind the brain, and this results in the f
mation of a linear series of segments, or myotomes (F
43), extending the length of the body of the embryo. T
primitive segmentation persists in a modified form in ad

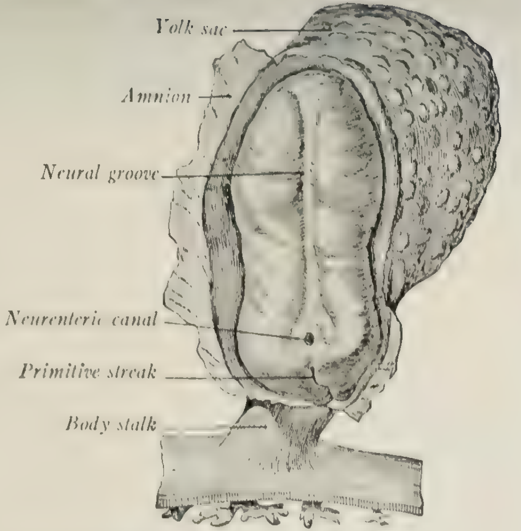


FIG. 42.—HUMAN EMBRYO OF 1.54 MM. × 33.

(von Spee.)

The amnion has been cut away to show the neural groove.
From Prentiss and Arey, *Embryology*.
By permission of W. B. Saunders & Co.

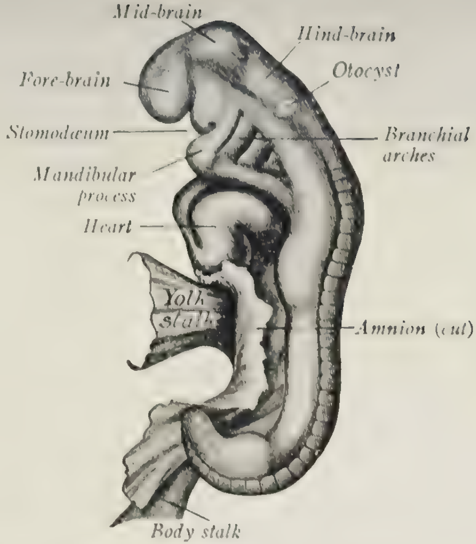


FIG. 43. HUMAN EMBRYO OF 4.2 MM. × 15.

(His.)

Lateral view, showing brain vesicles, branchial arches, between which are the gill clefts, and, to the right, muscle segments (myotomes).
From Prentiss and Arey, *Embryology*.
By permission of W. B. Saunders & Co.

an in the serial arrangement of the vertebræ, the ribs, and
ie spinal nerves. In the lateral mesoderm a cavity develops
hich is the beginning of the body cavity, or cœlom. This
ter contains the heart, lungs, and viscera of the abdomen.
his cavity splits the mesoderm into two layers. The outer
yer joins with the ectoderm to form the body wall, and the
ner layer with the endoderm to form the wall of the ali-
entary canal which in time becomes entirely enclosed by the
esoderm and ectoderm of the body wall. The human
nbryo at this stage has acquired the characteristics of a typi-
l vertebrate.

Later Prenatal Development

The Nervous System. The hollow neural tube early ex-
ands at its anterior end into three sacs (Fig. 44), the primary
rebral vesicles, or as they are often called the fore-, mid-,
d hind-brain, and later the first and third sacs partially sub-
vide making altogether five enlargements. From the walls
these five sacs and from the remainder of the neural tube
e developed all parts of the brain and spinal cord and nearly
l parts of the cranial and spinal nerves which run to the
ripheral regions of the head and body. The developing
ain increases in length rapidly and bends in three places, the
rvical flexure remaining permanently. A small sac grows
it on each side of the hollow anterior brain vesicle and ulti-
ately forms the retina of the eye (Fig. 44), which is thus a
irt of the brain projected to the surface of the head so the
ght can reach it. By thickenings, thinnings, and outgrowths,
different parts of the walls of the cerebral sacs, and by the
evelopment of myriads of nerve cells and fibers growing in
any directions, the various parts of the brain are ultimately
rmed. Another sac grows out from each side of the fore-
ain in front of the developing retina which (Fig. 44), in
an especially, possesses the power of extensive growth. This
c expands in all directions but especially backward, spreading

over the rest of the brain tube, and ultimately forming the cerebrum, which is so large in man in comparison with the lower animals. All of this sac, except the lower part, as well as the parts of the adult brain formed from it, is known as the mantle, or pallium (Fig. 45), the olfactory portion of which is named the archipallium since in evolution it is the oldest part of the brain, while the rest, being a more recent addition, is called the neopallium. The latter is most extensively developed in man and forms the major part of the cerebrum.

The early condition of the neopallium in man represents about the extent of the pallium in the adult fish (Fig. 45). As it grows further backward it corresponds to the extent of the pallium in the next higher class of vertebrates, the amphibians, and later to the extent in reptiles. Finally, as it begins to cover the cerebellum, we have the extent of the pallium as found in lower mammals and when it covers the cerebellum completely we have the human pallium. Thus we see that the pallium in its development in man passes through successively the various stages represented in the adult forms of the different vertebrates, starting with the fish and terminating with the mammalian type (Fig. 45). Similarly the structural unit of the nervous system, the nerve cell, or neurone (Fig. 46), passes in its development in man from the very simple neurone of the fish through the increasingly complex forms of the various vertebrates to its greatest complexity in man.

The sensory nerves (Fig. 47), which connect the skin and the various peripheral sense organs to the central nervous system, develop by a separation of serial groups of cells from the dorsal portion of the neural folds. From each of the cells in these groups two processes grow out. One grows into the central nervous system and the other pushes its way among the cells of the embryo until it reaches the sensory structures at the periphery. The motor nerves (Fig. 47) which control the muscles, on the contrary, grow out from cells situated in

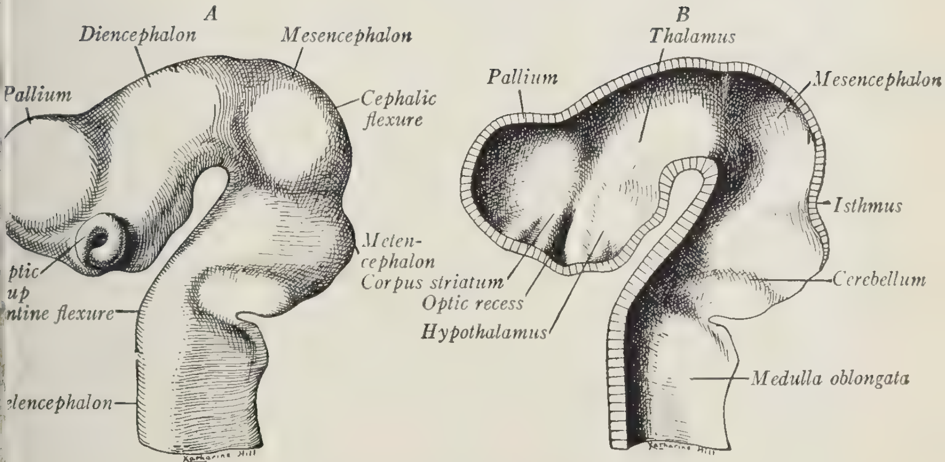


FIG. 44.—DEVELOPING HUMAN BRAIN

From a 7 mm. embryo, showing the vesicles.

A, lateral view; B, median sagittal section. The fore-brain consists of the telencephalon (region labelled pallium) and diencephalon; the mid-brain consists of the mesencephalon, and the hind-brain of the metencephalon (cerebellum) and myelencephalon (medulla oblongata). The portion of the fore-brain which becomes the retina of the eye is indicated in A as the optic cup.

From Prentiss and Arey, *Embryology*.

By permission of W. B. Saunders & Co.

the anterior part of the spinal cord and thread their way among the embryonic cells till they reach the proper muscle, where they break up into fine fibrils which become embedded in ts fibers. Nerve fibers, therefore, are merely the very elongated processes of nerve cells. How these fibers are directed o their proper terminations among the myriads of cells, whether by chemical attraction or other force, and so seldom go astray, has never been determined.

Before the nerves function they become surrounded by a translucent covering, called the myelin sheath, which is assumed at different periods during development, in the various parts of the spinal cord and brain. In general the myelin sheaths are assumed first by the peripheral sensory and motor nerves, thereby completing the reflex mechanism which in man occurs at about the sixth month of prenatal life. Following this the different groups of cells in the spinal cord are associated by the development of the myelin sheaths on the connecting nerves, thus arranging for association of the reflex actions. Still later the nerves connecting the spinal cord with he cerebellum myelinate, thus completing the mechanism for oördination of movements. Then the afferent nerves, which connect the spinal cord with the brain, assume their myelin sheaths, thus preparing the pathway for sensory impressions. Not until after birth, however, are the efferent tracts connecting the cerebrum and spinal cord myelinated, thus placing the erebrum in control of the parts below and completing the motor pathway. This late completion of the motor tracts in man explains the great helplessness of the human infant at irth, a condition which is in striking contrast to that in many f the lower animals. It is believed that the assumption of the myelin sheaths in the various association tracts of the cerebrum continues during the period of growth and perhaps until forty ears of age. As no brain cells are ever formed after birth, the increasing myelination of the nerve fibers is the chief structural change in the brain that can be correlated with the educational process.

The Eye. The eye develops from three sources. The retina, as noted above, is a direct outgrowth from the forebrain on the side of the head. The lens is an ingrowth from the ectoderm, and the sclerotic and choroid membranes, which form protective coverings enclosing the retina, are mostly differentiated from the mesoderm. Up to the sixth month of prenatal life a membrane stretches across the pupil of the eye which sometimes fails to disappear and thus causes blindness. Also the eyelids are grown together until about the same period, but in man, unlike the condition in certain other animals, such as kittens, a separation of the lids occurs before birth.

The Ear. The internal ear forms as a saccular ingrowth from the ectoderm on the side of the head. This invaginated sac becomes greatly modified but eventually forms the semicircular canals, which preside over the function of equilibrium, and the highly developed cochlea which is concerned with hearing. The internal ear is regarded as a specialization of a par of the lateral line sensory organs of the lower vertebrates, which in the fish is concerned with balancing and movemen only. The added cochlea, which is present in terrestrial animals, forms the organ of hearing.

Alimentary Canal. The alimentary canal, as stated above, is early folded off from the yolk sac as a tube lying under th notochord of the embryo. Both ends of the tube are closed fo a time, but long before birth an anterior and posterior connection with the external surface of the embryo has been made. At the anterior end of the body on each side of the neck, four crevices (Fig. 43) appear in the early embryo which, in th lower vertebrates such as the fish, open directly into th pharyngeal region of the alimentary canal and form the gi clefts. In man, however, these crevices never go on to th

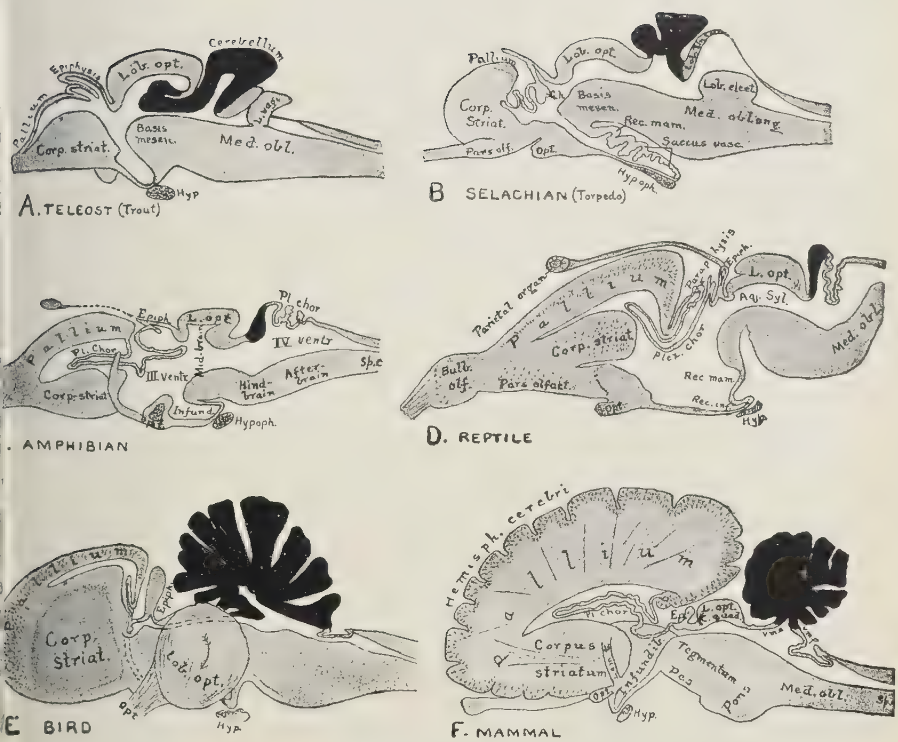


Fig. 45.—THE PALLIUM AND CEREBELLUM IN THE BRAINS OF VARIOUS VERTEBRATES

The cerebellum is in black.
After Edinger. From Bailey and Miller, *Embryology*.
By permission of William Wood & Co.

formation of gill clefts but soon disappear. Their presence, however, is indicative of a fish stage in his development. The lungs, which are the permanent respiratory organs (Fig. 48) of man, are developed from the upper end of the alimentary canal by the formation of a single hollow sac. This later ifurcates to form the rudiments of the right and left lungs and hese by repeated branching develop the highly ramified, tubuar structure of the adult lungs. The early simple, sac-like ung of the human embryo is similar in structure to the permanent, saccular lung of the adult amphibians.

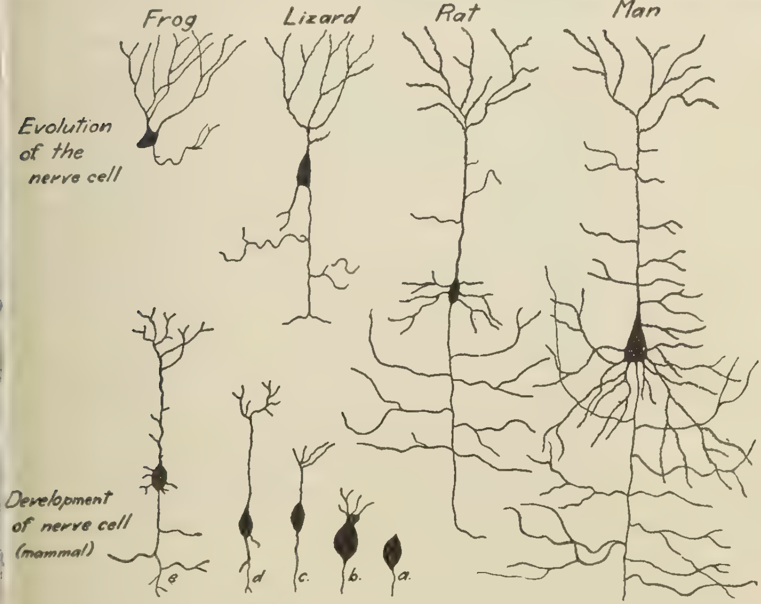

Frog
Lizard
Rat
Man
Evolution of the nerve cell
Development of nerve cell (mammal)
e
d
c.
b.
a.

FIG. 46. THE NERVE CELL
Its individual and evolutionary development.
After Cajal.
Redrawn from Donaldson, *The Growth of the Brain.*

From the neck region of the alimentary tube, three other rgans develop as branching outgrowths, all of which finally orm organs of internal secretion, namely the thyroid, the parathyroid, and the thymus glands (Fig. 48). Another important endocrine organ, the pituitary body, or hypophysis, has a double origin in that a portion of it develops as an upgrowth from the ectoderm which lines the extreme anterior end of the alimentary canal, or buccal cavity, and another portion, which fuses with the former, develops as a downgrowth from the brain. These glands, through their internal secretions, or hormones, influence development in various ways. All of them ultimately lose their connection with the alimentary canal. The thyroid gland moves down the ventral side of the neck and stops just above the thorax. The thymus, which in the calf is commonly called the sweetbread, descends into the thorax until it lies just above the heart. Early in prenatal life the glandular structure of the thymus disappears and a lymphoid tissue, such as we find in the tonsils, takes its place. The thymus continues to grow until the time of puberty and then gradually diminishes in size, disappearing usually in early adult life. This same remarkable history of the thymus is found in other mammals as well as in man. Little is known definitely with regard to the function of this organ.

Lower down the alimentary canal, just below the spindle-shaped enlargement which represents the developing stomach, two other organs grow out and, by repeated branching, form the liver and pancreas (Fig. 48). These always remain in connection with the alimentary canal by ducts which carry their secretions. The pancreas develops as two outgrowths which fuse, but usually only one of the ducts persists. Occasionally, however, both persist in man, and the pancreas pours its secretion into the intestine by two ducts instead of one. The explanation of such cases undoubtedly lies in the double origin.

The Vascular System. The heart differentiates from a portion of the mesoderm lying underneath the pharynx in the head region of the embryo. Two straight tubes are first formed (Fig. 49). These quickly fuse for part of their length form-

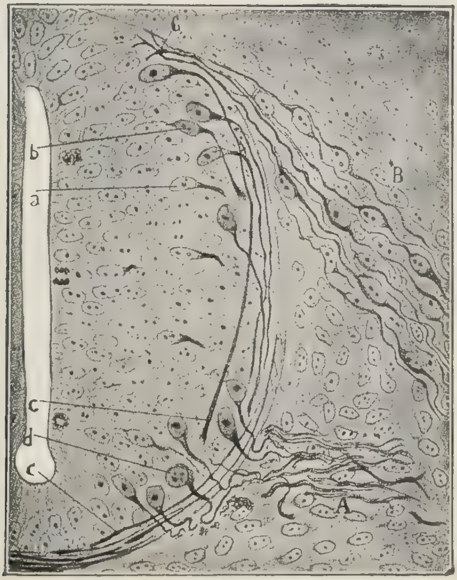


FIG. 47.—SPINAL NERVE

Transverse section through the spinal cord of a 76-hour chick embryo showing early development of a spinal nerve.

A, motor root; B, sensory root; C, bifurcation of fibers of sensory root; a, b, c, d, neurones in various stages of differentiation.

After Cajal. From Bailey and Miller, *Embryology*.

By permission of William Wood & Co.

ng a single tube which is bifurcated at each end. At this stage f development, the human heart resembles that found in the dult of the lowest vertebrates. Later the single tube of the leveloping heart partially subdivides into two cavities, the uricle and the ventricle, and it now resembles the heart of he adult of the next higher vertebrates, the fish. The auricle s then subdivided into two cavities, and the human heart of hree cavities resembles the fully developed heart of the next igher vertebrate, the amphibian. Later the ventricle is sublivided and the human heart contains four cavities, which is haracteristic of the adult heart of the highest vertebrates. hus it is evident that the human heart in its development asses through stages representing the different adult stages f the various ascending vertebrate classes. This again is an llustration of the so-called Law of Recapitulation, which holds n essence that man in his individual development repeats the volutionary history of the race, or that "ontogeny repeats hylogeny."

The blood vessels, consisting of the arteries, capillaries, and eins, are tubes which differentiate from the mesoderm cells n all parts of the body and become connected with the heart. he blood cells, which are present in countless numbers in the lood, likewise are derived from mesoderm cells, and we find hat the red blood cells of the human embryo when first formed re large and nucleated. In this stage they resemble those f the fishes and amphibians; later their structure is similar to hose of the reptiles. Finally, before birth, they become in nan, as in all mammals, non-nucleated and biconcave.

The complete natural history of the human red blood coruscles has never been learned. It is known that they are contantly formed in the adult from the cells of the red marrow n the ends of the long bones and that they are nucleated at irst but lose their nuclei before they enter the circulation. lthough it is believed that the corpuscles are constantly being destroyed, little is known as to where or how the destructive process occurs. Sometimes they seem to be destroyed much faster than they are formed and this results in a great reduction of the number of the red blood cells in the body from

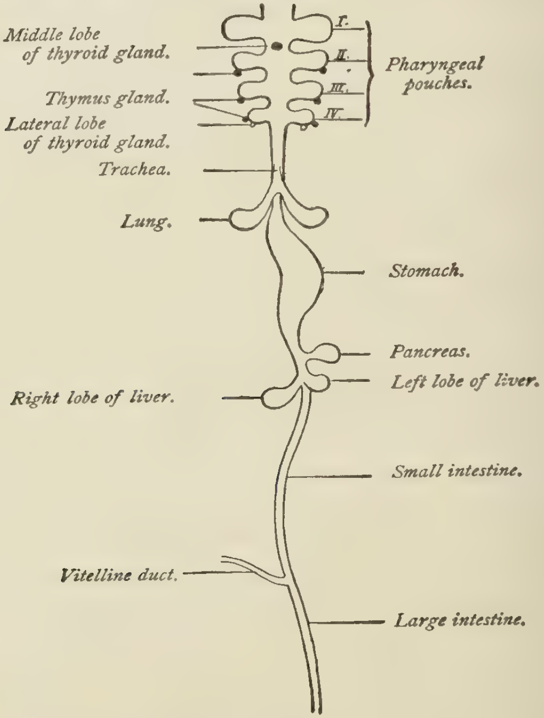


FIG. 48. ORGANS DEVELOPING FROM THE RUDIMENTARY ALIMENTARY CANAL

After Bonnet. From Heisler, *Embryology*. By permission of W. B. Saunders & Co.

5,000,000 to perhaps 1,000,000 per cubic millimeter, together with the appearance also of a certain number of the embryonic type of nucleated red cells in the blood stream. Evidently the immature cells are drawn into the blood stream in the endeavor to make good the excessive loss. This is the condition which exists in that quite fatal disease, pernicious anæmia.

Reproductive System. The gonads, in which the germinal cells form, are developed in the body cavity just at the lower end of the kidneys, probably from mesodermal cells, and early begin to move downward in the abdomen. In the female they go as far as the pelvic cavity where they remain. In the male they pass through a canal in the lower part of the abdominal wall, called the inguinal canal, to the exterior of the body. Similar migrations of the gonads occur in most mammals. The reasons for these migrations are not known, but the inguinal canal remains as a weak spot in the abdominal wall and under special stress may permit loops of the intestines to pass through, thus forming a hernia. This is the penalty man is still paying for the lack of structural adjustment to the upright position.

The external genital organs develop in a similar way in both sexes and no structural distinction is to be observed until near the beginning of the third month of fetal life. At this time the indifferent sex condition begins to develop into one sex or the other by the greater growth of some parts and the partial suppression of others, depending upon the sex to be formed. In rare cases the indifferent condition of the sex organs may persist permanently in either sex, a condition known as spurious hermaphroditism, which has particular interest to criminologists and sociologists. The urinary system develops in close relationship to the genital system and, before the permanent adult condition is reached, passes through a remarkable series of changes, many of which are typical of the permanent adult condition in the lower vertebrates.

The Muscles. As noted above, the mesoderm, which lies along each side of the developing spinal cord, becomes transversely divided into a linear series of segments (Fig. 43). This process begins when the embryo is about two weeks old and continues until a total of thirty-eight segments are formed which extend the entire length of the embryo. From these segments are developed all the muscles of the body, the axial part of the skeleton, and the membranes surrounding the brain and spinal cord. Although the muscles are at first

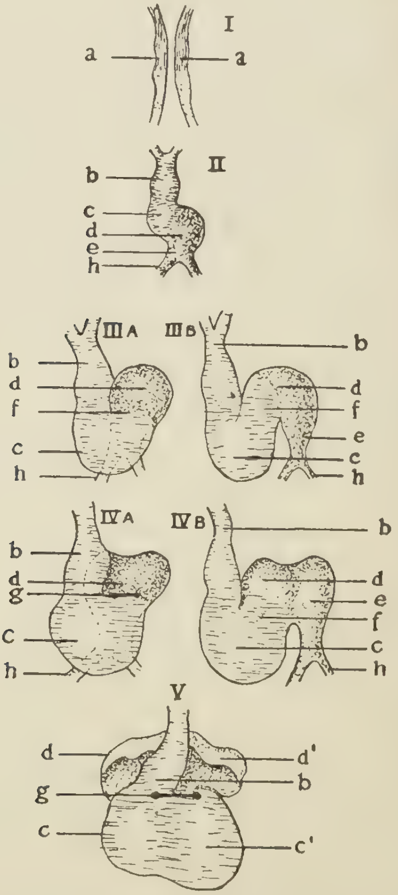


FIG. 49. THE HUMAN HEART

Diagram showing its development and changes of form and external appearance at different stages.

Modified from His's models.

Figs. IIIB and IVB are side views; the others are front views. a, primitive ventral aorta; b, bulbus cordis; c, ventricle; c′, left ventricle; d, auricle; d′, left auricle; e, sinus venosus; f, atrio-ventricular canal; g, position of orifice of atrio-ventricular canal; h, vitelline vein.

Redrawn from Cunningham, *Anatomy.*

eparate masses, by a process of fusion of the segments and then a later splitting, either lengthwise or tangentially, the ong, flat muscles in the front and back of the body are formed. Also many muscles shift from their early positions to some uite distant place. This is the case, for example, with the muscular diaphragm, which forms in the neck and is supplied by a nerve from this region but which, during development, moves posteriorly dragging its nerve with it, until in its final position it separates the thorax from the abdomen. All of his differentiation and shifting of muscles has been completed some time before the child is born and therefore is not produced by any functional necessities after birth, but is due o heredity.

The Limbs. Until the beginning of the fourth week of development, man is a limbless vertebrate (Fig. 52). The rudiments of the limbs then grow out as buds from the side of he body and, as they elongate, five projections appear at the nd of each of the buds which represent the developing fingers nd toes. This peripheral cleavage into five parts perhaps s representative of the five main segments of the body from which the limb projects. Inasmuch as the five-fingered, or pentadactyl, limb is the common vertebrate type, it is believed hat polydactylism, or an extra number of fingers or toes, is not a reversion to an ancestral form but is due to hereditary factors as shown in Chapter XIII. (See pages 433–6.)

The Skeleton. The skeleton is preceded in very early prenatal life by two kinds of material, cartilage and membrane. While most of the bones of the skeleton are ossified from carilage, the bones of the cranium are largely developed from membrane. The cranial bones begin ossification at their enters near the end of the second month of prenatal life; the growth of the cranium being due chiefly to additions at the dges of the bones. In the long bones, like the femur and humerus, which are mapped out in cartilage, the centers of ossification appear about the eighth week of prenatal life in the center of the shaft, and, at birth, while the shaft is bone, both extremities are still cartilaginous.

The Skin. The outside portion of the skin, or epidermis, is derived from the ectoderm, while the deeper portion, or dermis, is developed from the mesoderm. The human skin at the end of the second prenatal month is translucent and has many points in common with that of fishes and amphibians. In the third month a delicate, superficial, horny stratum appears, a stage which has been held to represent the evolution from an aquatic to a terrestrial form of life.

Hairs are outgrowths from the epidermis and are developed in groups and lines. Their arrangement can best be explained on the supposition that originally the skin was covered by scales and that the hair grew out in groups at their tessellated junctions as is found in certain of the edentates. The skin of man, in comparison with that of the other primates, is comparatively hairless, which is probably a recently acquired character. At the seventh month of prenatal life the chimpanzee and gorilla have well-developed hair on the scalp, eyebrows, and lips, while the rest of the body is covered with fine hair. This is also the condition of the human fetus at a corresponding period. The hair slopes in man are also very similar to those of the apes. Some hairs, such as those present in the eyebrows, perhaps originally had a sensory function and, in general, hair appears to be a modification of certain glandular and sensory structures found in the skin of the amphibians. Accumulated evidence shows that the development of the hair is regulated, at least to some degree, by an internal secretion of the thyroid and sex glands.

Face and Nose. The face is developed from a series of paired processes surrounding the primitive mouth (Fig. 50). These grow in from the sides toward the mid-ventral line where they normally fuse by the third prenatal month, by a

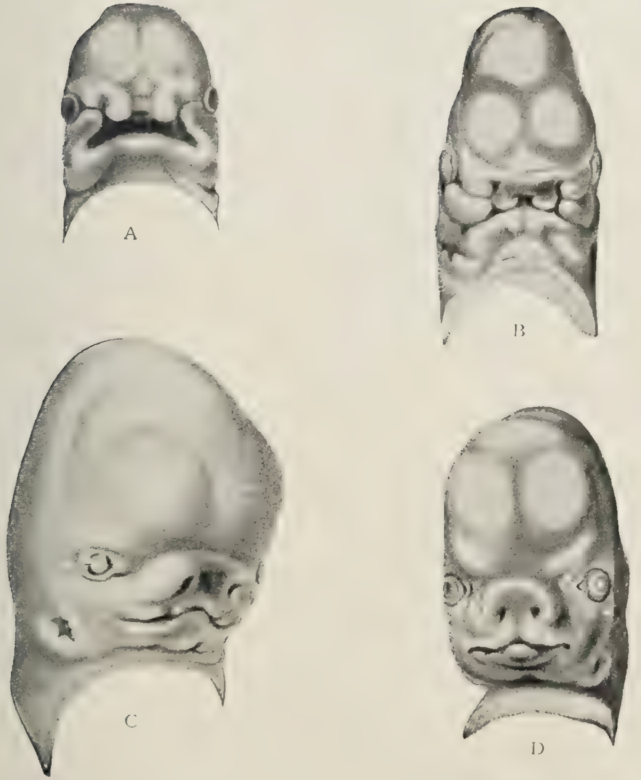


FIG. 50.—DEVELOPMENT OF THE FACE OF A HUMAN EMBRYO

(His.)

From Prentiss and Arey, *Embryology*.
By permission of W. B. Saunders & Co.

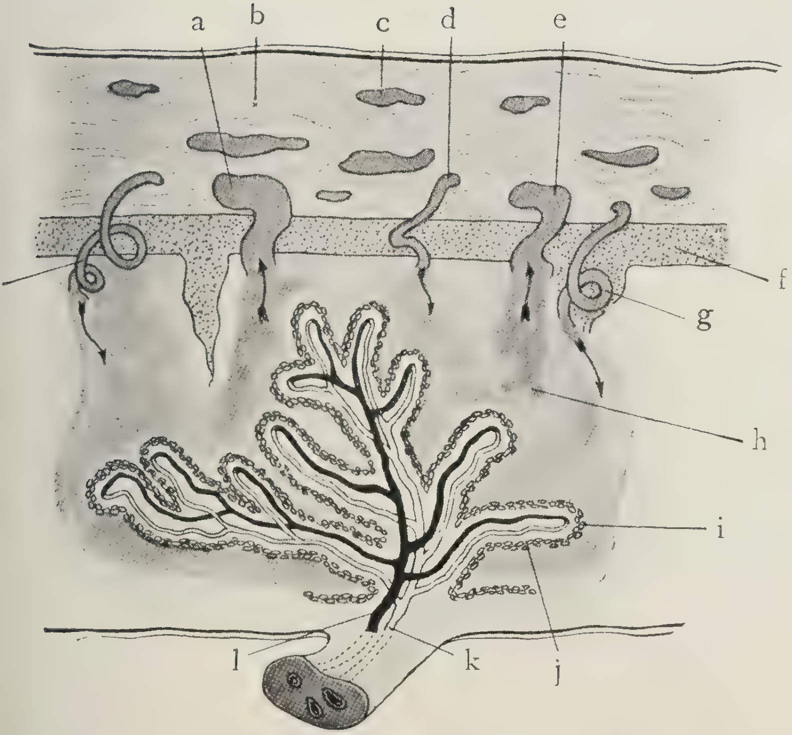
iethod somewhat akin to the healing of wounds, to form the ose and lips. A failure of proper fusion of these processes esults in harelip and various other facial deformities.

In the development of the human nasal cavity a recapitulaion of the conditions present in the various classes of verterates is to be noted. At the end of the third week of fetal fe the rudiments of the olfactory organ appear as two thickned plates of ectoderm which are in contact with the under urface of the fore-brain. A week later these plates become epressed and are found at the bottom of the olfactory pits. his condition is similar to that found in fishes. Two weeks ater the depression has deepened and a nasal cavity is formed hich is somewhat similar in structure to that found in the ir-breathing or lung fishes. By the seventh week this primiive nasal cavity has rapidly enlarged and a communication as been made with the mouth as in amphibians. The mamialian condition is reached by the third month. At this time he roof of the mouth is completed by the growth to the center nd fusion of two lateral shelves. A failure of these shelves o unite produces cleft palate.

The teeth are formed by local outgrowths of the ectoderm nd mesoderm lining the mouth, the enamel being formed rom the ectoderm, and the dentine and pulp from the mesoerm. The human molars with their several cusps have volved from the simple conical teeth of fishes and reptiles ither by a process of partial fusion or by an outgrowth of usps from the conical tooth.

The Prenatal Nourishment of the Embryo. During preatal life the fetus is enclosed in a fluid-filled sac, the wall of hich is composed of two membranes, the inner called the mnion and the outer the chorion, which serve for protection nd nutrition (Fig. 41). The development of an embryo *in tero* is dependent upon its ability to secure nourishment and o eliminate certain wastes. In order to do this it must form a contact with the maternal blood supply in the walls of the uterus. It appears that, in this early stage, the outer layer of embryonic cells is able to secrete a ferment, or enzyme, which actually eats away, or digests, a portion of the uterine wall with which it is in contact. This process furnishes the embryo with a temporary supply of food which can be absorbed by its cells and also enables it to imbed itself completely in the uterine wall where it is surrounded with extravascular maternal blood, the result of the erosion of maternal blood vessels. In a short time a certain region of the outer layer of cells together with the underlying chorion becomes modified to form a highly specialized structure, the placenta, through which an interchange of materials between the mother and embryo can take place. The fetal placental tissues become actually fused with the uterine wall (Fig. 51), and the underlying tissue of the latter is gradually eroded to such an extent that the finger-like processes, or villi, of the fetal tissues of the placenta, which project into the maternal tissue, are surrounded by intervillous spaces of considerable size which are filled with the maternal blood (Fig. 51). Although the placental villi are richly supplied with fetal blood vessels there is never any direct connection between the maternal and fetal blood vessels in the placenta, and no nerves pass from the mother to the child. The interchange of materials, oxygen and food from the maternal to the fetal circulation, and carbon dioxide and liquid metabolic wastes from the fetal to the maternal, all takes place by osmosis and specific selection. The structure of the placenta in the different mammals shows considerable variation. That found in the anthropoid apes is very similar to the human type.

The maternal and fetal blood streams are separated by th embryonic tissue of the placental villi (Fig. 51). This separa tion can be proved by the microscopic examination of the con tents of the fetal vessels in the placental villi and the materna



IG. 51.—THE RELATION OF THE FETAL TO THE MATERNAL BLOOD IN THE PLACENTA

Arrows indicate the supply and exhaust of the maternal blood in the large intervillous spaces.

a, sinus of uterine vein; b, muscle tissue of uterine wall; uterine vein; d, terine artery; e, sinus of uterine vein; f, decidua basalis; g, uterine artery; h, ntervillous space filled with maternal blood; i, syncytium; j, villus; k, umbilical ein (fetal); l, umbilical artery (fetal); m, uterine artery.

From Prentiss and Arey, *Embryology.*
By permission of W. B. Saunders & Co.

ood in the placental sinuses in the early stages of develop-ent. Many nucleated red corpuscles which are found only the blood of the fetus will be seen in the vessels of the cental villi but there are none in the placental sinuses. rther, the vessels in the placental villi can be injected from fetal but not from the maternal blood vessels.

That gases can be transmitted from the maternal to the al circulation is shown by the fact that the blood in the um-ical vein, which carries blood from the placenta to the fetus, redder and contains more oxygen than the darker blood of umbilical artery, which carries blood from the child to the centa. Also ether or chloroform administered to the other can be demonstrated in the blood of the child.

Substances in solution also can pass from the maternal to fetal blood. This is indicated by the fact that the child ows. Also it has been experimentally demonstrated in the se of many drugs that when they are administered to the other they will be found in the blood of the child. Among ese drugs are bromide of potassium, arsenic, strychnine, inine, and morphine.

The work of recent observers seems to show that fats and oteins are not passed unchanged through the walls of the cental villi from maternal to fetal blood, but are broken wn into simpler compounds and later recombined, thus mak- the process of absorption in the placenta somewhat analo-us to that occurring in the intestine. The placental tissue parently has not only the power to change some substances t also the power of specific absorption. Proteolytic, lipo-ic, and glycolytic ferments have been demonstrated in the cental villi, also a ferment which changes certain of the ino acids into ammonia.

Observers now generally agree that, while the placenta ually acts as an efficient filter against bacteria, occasionally cteria may be transmitted from mother to child as has been known to occur in some cases of typhoid fever and, in rar instances, of tuberculosis. On the contrary, it has been demonstrated that the toxins and antitoxins of diphtheria, tetanu and typhoid fever readily pass from the maternal to the feta blood stream in the placenta. Furthermore, biologists agre that there is no foundation for the more or less general belie that maternal impressions are responsible for malformation in the child. It can be understood, however, that a general disturbance of the fundamental metabolic processes in the mothe may result in similar disturbances in the fetus and thus ma interfere with the normal developmental processes.

Birth. It has been seen that the human embryo is a parasite which engrafts itself on the maternal tissues and by th remarkable and highly specialized organ, the placenta, i supplied with nourishment and relieved of its wastes. Thi connection is normally retained for a period of approximatel nine months, at which time the 'host,' for reasons largely unknown, refuses longer to support the 'parasite.' Rhythmi contractions begin in the walls of the uterus. These increas in strength and frequency and finally result in the birth of th child. In separating the placenta and tearing the large maternal vessels of the uterus, without causing an excessiv hemorrhage, nature performs a wonderful surgical operation The moment the child breathes and the lungs expand, th course of the circulation is changed. This change is due t the expansion of the lungs and the consequent large flow o blood to them. As the result of this, the opening between th two auricles (*foramen ovale*) closes, the course of the circulation in the heart is also changed and the blood, which wa formerly aërated in the placenta, is now aërated in the lungs Sometimes this interauricular opening fails to close in th proper manner and this permits a mixture of venous with arterial blood which causes a dark color in the skin and, therefore, what is commonly known as a 'blue baby.'

In the prenatal condition the child needs to produce very
tle heat because so little is radiated and the mother supplies
l of the necessary food and oxygen and removes all the
astes. After birth the radiation of heat is greater and the
ild is obliged to produce much more in order to maintain its
dy temperature. The alimentary canal must take in and
gest its own food; through its lungs the child must obtain
ygen and free itself of carbon dioxide, and its excretory
gans must remove its own wastes. It is evident, from the
ove, that there is a great contrast between the prenatal
d postnatal environment, and the fundamental changes in
rculation, nutrition, and excretion which occur at the time of
rth make this period a very critical one for the child.

At birth the child weighs about seven pounds, and is twenty
ches in height. Its upper extremities are relatively long, and
e lower extremities short. The legs are partly flexed, the
eat toe abducted and the soles of the feet turned in. The
tter is believed to be indicative of a persistence of the climb-
g position which existed in arboreal man. Additional evi-
nce along this line is to be found also in the remarkable
wer of the hand grip of the child during the first month of
s life. At this time the infant is able to hold its weight sus-
nded by its hands, a power which is later lost. When the
dy proportions of the newly born child are compared with
ose of the adult it is found that the child is four times its
ad height while the adult is eight times; that the upper and
wer extremities of the infant are equal in length while in the
ult the lower extremities are longer than the upper. The
ng arms, short legs, flat nose, inverted feet, and lack of
rvical and lumbar curves in the spinal column of a newly
rn infant constitute a remarkable series of structural re-
mblances to the ape which later disappear as the adult condi-
on is reached. The child at birth can feel, see, taste, and
ffer pain but it is deaf for about twenty-four hours. Its

most striking characteristics, in contrast to the lower animal are its helplessness and educability. Its helplessness has u doubtedly been an important factor in the development of th family, while the long period of growth before maturity reached has exerted a great influence in the development c man's psychic powers, which distinguish him so markedly fro all other animals.

Statistics of various animals show that the proportion c male and female births is approximately equal; the ratio i man being about 106 males to 100 females. Multiple birth are the usual rule in most of the lower mammals but not in th primates. Occasionally, however, it occurs and in man eve sextuplets have been recorded. There have been some 50 theories proposed as to the cause of sex determination an as to methods for controlling it, but the accumulated evidenc of the last few years clearly shows that sex is determined a the time of fertilization, just as are all somatic character and that it cannot later be changed by any means. Inasmuc as the ossification of the bones of a female embryo precede slightly that of the male embryo, a radiograph may perhap aid in ascertaining the sex of the child before birth.

If we summarize the facts regarding man's early develo ment, which are given above, it is evident that he starts hi development as a unicellular animal, becomes a metazoan c the invertebrate type, develops the structure of a vertebrat and ultimately becomes a mammal. Many of the structure of his body pass through temporary stages which are typical o the adult condition in various classes of the vertebrates an in general, his organs are developed in a manner similar t that in other animals. Man's development, however, paralle that of the anthropoid apes for a longer time than that o other mammals and at birth the child has ape-like characte that later disappear. These facts of human developme associate man closely with the anthropoid apes and give ev

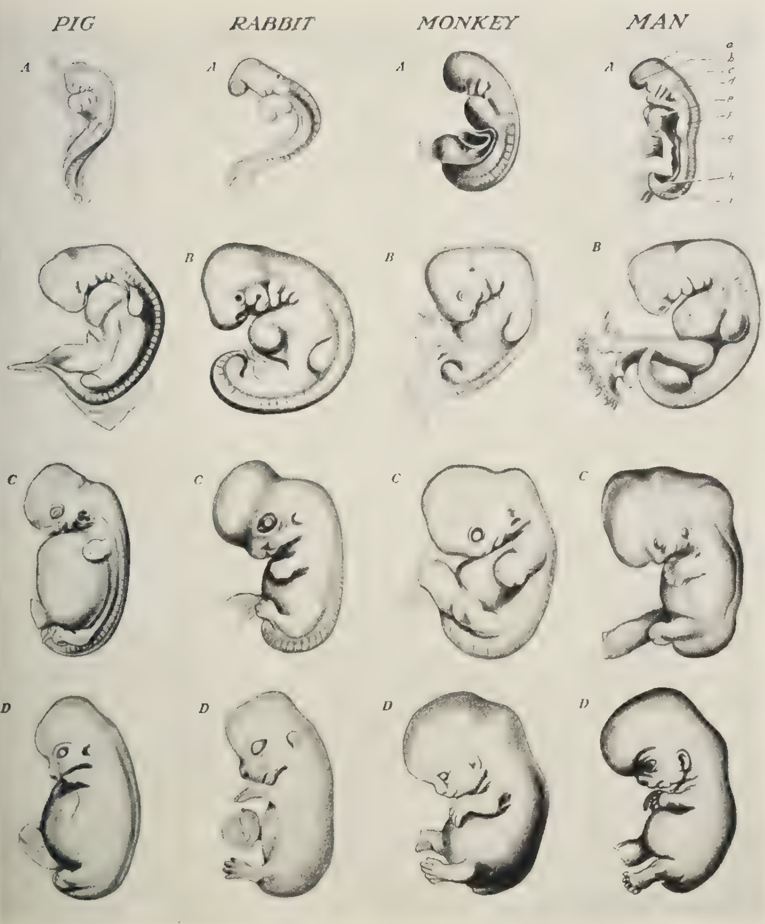


FIG. 52.—EMBRYOS OF THE PIG, RABBIT, MONKEY, AND MAN

Comparison at corresponding stages of development. The embryos of each animal are arranged in the vertical columns according to age, beginning with the youngest stage at the top. Stage A of the human embryo is fully labelled, and the corresponding structures in the other embryos can be noted.

a, head region; b, eye; c, ear; d, gill slits; e, heart; f, fore limb; g, primitive muscle segments; h, hind limb; i, tail region.

Slightly modified from K. Guenther, after Keibel.

lence that the latter reproduce, in many respects, a compara- ively recent phase in the history of human evolution.

POSTNATAL DEVELOPMENT

In the final analysis, growth in any living organism is the esult of the division of a cell into two daughter cells each of hich, when first formed, is half the size of the original cell. he daughter cells very soon, by the process of intussuscep- on which undoubtedly involves complex physico-chemical rocesses, grow to the size of the original cell and then the rocess can be repeated. In prenatal life, the embryonic cells, n general, divide comparatively rapidly and, as a rule, are not s large as in postnatal development. The increase in size fter birth is believed to be due primarily to a general increase n the size of the cells of the body rather than to the formation, y cell division, of additional cells. Development is therefore ccomplished by cell division, cell enlargement, and cell differ- ntiation.

The ultimate size of an animal depends both upon the rate nd the duration of growth. Minot has shown that man ecomes larger than the rabbit, not because of a more rapid rowth, but because he grows for a longer period of time. he rabbit, on the other hand, becomes larger than the guinea g because of a more rapid rate of growth. Large animals, ith few exceptions, continue to grow during a longer period nd live longer than do small animals. Statistical studies show hat the rate of growth is most rapid in early prenatal life and eadily diminishes until birth. During the prenatal period the human embryo the weight increases more than 5,000,- 00 times, while after birth the increase is only 20.6 nes. As the rate of growth is a constantly decreasing ne, its cessation seems to be the final term of a diminishing ries. During the most rapid period of growth the cells have rge nuclei but, with advancing age, the cytoplasm relatively increases and this change in the relative size of nucleus an cytoplasm constitutes the chief structural difference betwee the cells of the young and of the old. A decreasing rate growth is also accompanied by a diminution in the wate content of the body, as is shown by the fact that in the fir month of prenatal life the percentage of water in the boc is 97.5 per cent, at birth it has become 74.7 per cent, and maturity 58.5 per cent.

While man and the higher vertebrates have a definite peric of growth some fishes and amphibians continue to gro throughout life. The forces which stimulate or inhibit growt are largely unknown. Evidence is accumulating to show th certain of the internal secretions, notably those given off the thyroid and pituitary glands, play a large part in the co trol of growth. It is believed that too much secretion of th latter may increase the growth of local areas of the body suc as the hands and face. This condition is to be seen in the ra disease known as acromegaly. On the other hand, a dimi ished secretion of the thyroid results in a failure of growth the entire body as well as a lack of mental development, condition known as cretinism. Various factors such as u favorable climatic conditions, poor food, lack of proper pr teins and vitamines, and severe illness retard growth.

However, these factors do not offer any explanation as why most animals stop growing after reaching the size of th species. A mouse never grows to the size of an elephant, n does an elephant remain as small as a mouse. It is apparen that there is a fundamental hereditary factor involved which some way, possibly through the internal secretions, contro growth. That this hereditary influence has not always r mained constant is shown in the size variation of the sam species in different geologic ages. This is notably shown the evolution of the horse. The question of growth is close associated with the power of regeneration, that is, the abilit

f an animal to replace lost parts. The power of regeneration
an animal, in general, is found to be in inverse ratio to the
egree of specialization, or differentiation, which it exhibits.
or example, among the lower vertebrates, the amphibia are
ble to regenerate entire limbs, whereas in the more highly
ecialized animals such as man this power of regeneration
present only in certain tissues, notably the connective and
pithelial, by the agency of which wounds are healed. Cancer
generally regarded as a localized lawless and unrestrained
rowth of epithelium, the cells having become parasites and
ttacked the host. The only cure thus far discovered is an
arly destruction or removal of the abnormal parasitic cells.
he causation of cancer apparently lies in the disturbed bal-
nce of the forces stimulating and restraining growth in the
ffected cells and is probably essentially a faulty cellular
emistry.

The child sits erect by the sixth month, creeps by the tenth
onth, and walks by the fifteenth month, thus passing from a
adrupedal gait to the erect position in a few months, an
complishment which in evolution may have occupied ages.
ll parts of the child do not grow at the same rate and, as
result, the body proportions continually change during
owth (Fig. 53). Even the shaping of the features is due to
e different rates of growth of the various parts of the face.
omparing the condition at birth with that of maturity it is
und that while the head doubles in height, the body increases
ree times, the upper limbs four times, and the lower limbs
e times. These changes in the body proportions are well
own if we compare the adult proportions with the pro-
rtions of the child when expanded to the height of the adult.
ch a comparison will show, as has been previously noted,
at the head of the adult is relatively smaller, the arms
orter, and the legs longer (Fig. 53).

Likewise it is known that various organs grow at different rates with the result that they bear a different ratio to the total body weight at different ages. Here is a field that needs much further study inasmuch as this changing relationship in size may have an important bearing on the incidence of disease at different ages. The studies which have been made on the relative growth of the different organs show that the same proportionate weight of the skeleton, fat, and skin, which i about 39 per cent of the total weight of the new-born, persist in the adult; that the relative weight of the organs of circula tion, respiration, and alimentation is about twice as large in the new-born as in the adult; that the weight of the muscles of the new-born is relatively one half as large as in the adult, and that the central nervous system of the new-born is relativel eight times as large as in the adult. It is possible that the ver rapid growth of the brain in early childhood accounts in part at least, for the nervous instability of that period.

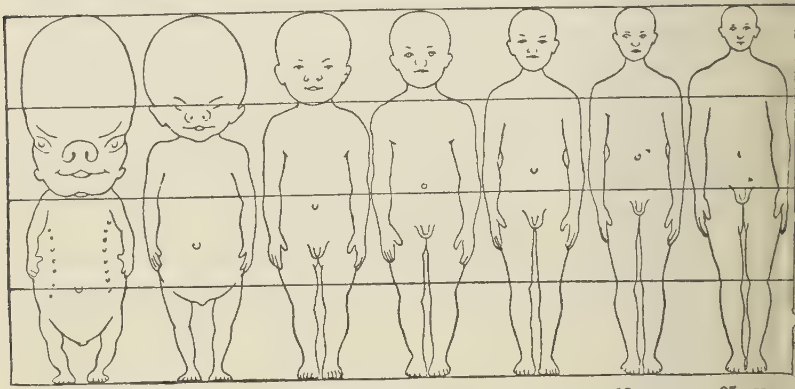


Fig. 53. CHANGES IN PROPORTION DURING PRENATAL AND POSTNATAL GROWTH
After Stratz. From Morris's *Human Anatomy*.
By permission of P. Blakiston's Son & Co.

Considerable data have accumulated with regard to th growth of bone. Membrane bones, such as certain bones of th cranium, grow by additions along their edges which form the sutures. Beginning at about forty years of age, when the brain stops growing, the cranial sutures disappear. In the long limb bones in early postnatal life, one or more centers of ossification appear in the terminal cartilages and form caps of bone. The growth in length occurs in the cartilage under the bony caps. This was shown experimentally many years ago by John Hunter, who inserted shot in the shaft and in the end cap of a femur in a young animal, and later found that the distance between them had increased. Usually by the twenty-first year these caps have joined to the shaft thus making any further growth in length impossible. The growth in the circumference of a bone takes place by additions under the outer fibrous membrane, known as the periosteum. This has been shown experimentally by feeding growing animals with madder, which gives a yellowish stain to the new bone.

The child, like the young of all mammals, is born without teeth. The first set, twenty in number, begins to erupt about the sixth month after birth and is completed when the child is nearly two and one half years of age. During the next few years the permanent teeth, thirty-two in number, are forming beneath the temporary teeth and also behind them, and, by the absorption of their roots, replace them. The first permanent tooth to erupt is the first molar which appears behind all the temporary teeth at the sixth year. By thirteen years of age all of the permanent teeth have erupted except the third molars, or wisdom teeth, which appear about the seventeenth year. The latter may be small in size, abnormally placed, appear late, or even fail entirely to appear.

A study of the growth curves for height and weight (Fig. 54), which have been plotted by averaging the results obtained from weighing and measuring many children at various ages, chiefly over five years of age, shows a general agreement of results. There is a loss of weight for the first few days after birth, the postnatal retardation. During the first year growth in both weight and height is rapid—the boy increasing

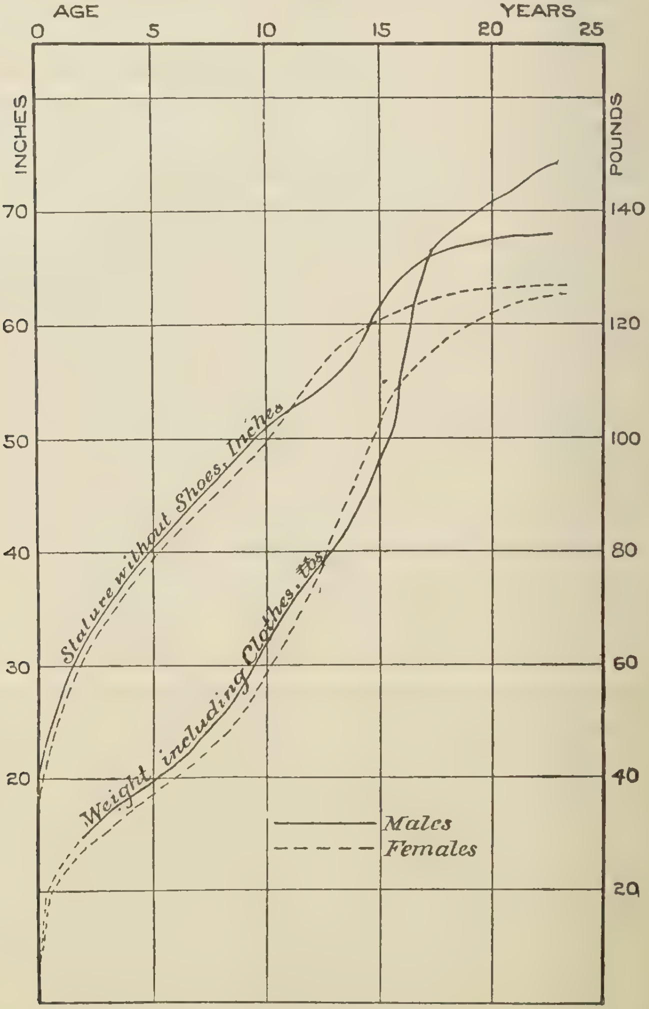


Fig. 54. GROWTH CURVES FOR INCREASE IN WEIGHT AND STATURE FOR BOTH SEXES
From Donaldson, after Roberts.

more rapidly than the girl—then the rate of growth goes on more slowly up to seven years of age. This is followed by a more rapid increase in growth rate up to about seventeen years in the boy and sixteen years in the girl, with a prepubertal acceleration present in both sexes. The growth rate then decreases to twenty-five years of age, at which time growth practically ceases.

During the early years the boy is slightly taller and heavier than the girl but, owing to an earlier prepubertal acceleration in the girl, the two sexes are equal in height at twelve years of age and for the next three years the girl is the taller. Similarly, at thirteen years of age, the two sexes are of equal weight and for the next three years, the girl is the heavier. After fifteen years of age the boy surpasses the girl in height and after sixteen years in weight. The average height for the people in the United States is about five feet and eight inches for men, and five feet and four inches for women. On the other hand some of the dwarf races of central Africa scarcely attain four and one half feet in height. The average weight of the male is 150 pounds and of the female 125 pounds.

Puberty. At puberty certain marked physical and psychic characters, known as the secondary sexual characters, develop which quite clearly distinguish the sexes. These changes, as experimental work on the lower animals has shown, are brought about by the internal secretions of the sex glands and can be prevented by their early removal. Also in the human female, after the climacteric when the internal secretions of the sex glands decrease, there is a diminution of the secondary sexual characters. In the male the growth in weight and height is usually greater, the brain and face grow larger, the vocal cords elongate rapidly, which causes the pitch of the voice to drop an octave, the beard develops, the muscles become larger, giving a more angular appearance to the surface of the body in marked contrast to the curves of the female, the waist is broader, the pelvis smaller, the shoulders less sloping, and the hands and feet larger. (See pages 244–247.)

SENESCENCE

The normal life cycle has three phases; development, maturity, and decline. Each of the first two phases lasts about thirty years in man, and the third should be at least of equal length. But this may be greatly exceeded as shown by the longest life yet recorded in modern times; that of Thomas Parr of England who was one hundred fifty-two years and nine months old when he died. Old age itself is a physiological condition which results from a state of lessened vitality and activity of the various organs. The essential factor in growing old is a progressive degeneration of the tissues, as a result of changes in the cells which compose them, thereby bringing about a gradually diminishing functional capacity of the various organs until, finally, the activity of some vital organ or organs ceases and physiological death results. Certain visible external structural changes in the body are increasingly in evidence as old age comes on, all of which are due fundamentally to degenerative changes in the individual cells of the various tissues. The hair turns gray, the skin loses its elasticity and becomes wrinkled. Extensive changes occur in the jaws which are due to a loss of the teeth, with a consequent absorption of that part of the jaw which held them, resulting in a return to the infantile type of jaw. The walls of the arteries harden (arteriosclerosis) and the blood pressure increases. There is a progressive loss of strength and elasticity in the muscles. Some of the cartilages may calcify, the bones become more fragile, the cranial sutures disappear, and there is a decrease in the stature. The near point of vision recedes, due to a loss in elasticity of the mechanism of accommodation. Changes also take place in the nervous system. These are associated with a shrinkage of the brain, due essentially to the atrophy of nerve cells in the cerebral cortex, and bring about a loss in muscular coördination and in memory, and a lack of acuteness in the senses. Normally, physical decadence occurs earlier than mental.

It is very difficult to distinguish between normal senile degenerative changes and those due to disease. For example, it seems impossible at present to tell whether the hardening of the arteries is to be considered normal or abnormal in old age. Also we know very little of the chemical alterations in the body which are associated with advancing age, except that a relative increase in the salt content has been found. In fact, he whole subject of senescence needs renewed investigation o determine what constitutes normal senile changes. The striking experiments of Steinach and others have shown, in he case of both the lower animals and man, that at least a emporary rejuvenescence can be produced in the old by engrafting the gonads or, in the male, by ligating the *vas deferens.*

There are three principal theories with regard to the bio-ogical significance of old age and natural death. The first theory is that old age is a pathological condition due to lack of internal adjustment to external environment. Metchnikoff was an advocate of this and held that there is a constant conflict between certain cells of the body, some trying to destroy the others which are essential to life. This they may accomplish if the cells acquire a lessened resistance as a result of the absorption of toxins released by certain bacteria in the intestines. Hence another species of bacteria, *Bacillus bulgaricus,* by interfering with the growth of the toxin-producing bacteria, becomes, according to Metchnikoff, a "fountain of youth." According to the second theory, which was advocated y Weismann, the higher organisms have acquired senility and natural death through natural selection as a character which is of advantage to the existence of the species. The third theory, which was advocated by Maupas and Minot, holds that, at fertilization, a stimulus is supplied to the developing organism which is gradually dissipated, during the later growth and differentiation, until finally none is left and the organism dies of old age. Whatever the facts may be with regard to the cause of senescence, it is evident that the phenomenon is common to all the metazoan animals.

Biologists have estimated that an animal should live from five to seven times the period of growth. This means that man should live to be from one hundred to one hundred and forty years old. The facts in regard to different animals, however, do not seem to support this view. Rubner has estimated that man requires about four times as many food calories for the period from the cessation of growth till the end of life as other mammals and he interprets this as meaning that the human cells have a much greater total capacity for obtaining energy from foodstuffs than those of other mammals. The cells seem to be able to make only a limited number of chemical transformations, after which physiological death ensues. Rubner believes that the cells in man can make a greater number of such transformations than those of most other mammals.

VESTIGIAL STRUCTURES

The normal life cycle of man having now been considered, attention should be given to another valuable line of evidence as to man's origin, namely, certain structural features known as the vestigial organs which, although practically functionless in man at the present time, are believed to be the remains of well-developed, functional organs in the past. A few typical examples may be noted.

At the inner corner of the eye is a fold of the conjunctiva, the mucous membrane covering the front of the eyeball, called the *plica semilunaris,* which is relatively larger during prenatal life. It is believed to be a reduced third eyelid, such as is regularly found in amphibia and birds, by which the eye is closed.

Man possesses muscles which are arranged to move the ear either as a whole or in part, but he has entirely lost the control of them or only exceptionally retains partial control. Probably when man assumed the erect posture with eyes looking forward the head became more movable and rendered unnecessary the mobility of the ear with the resulting loss of function in its muscles. At one period during prenatal development the human ear is pointed and resembles the ear of certain monkeys. This point persists in many people as a projection on the rolled or unrolled rim (helix) of the ear. It is known as Darwin's tubercle and is the vestigial remains of man's ancestral ear point.

Near the junction of the large and small intestine in man (Fig. 55) there is a narrow, blind process, about three and a half inches in length, known as the vermiform appendix. The appendix in man is a vestigial structure and represents the functionless, shriveled, terminal remains of the cæcum, the blind beginning of the large intestine. In an herbivorous animal, the cæcum is a large, nutritive organ of great importance. In carnivorous animals, the cæcum is reduced. The reduction of he terminal portion of the cæcum to form an appendix occurs only in man (Fig. 55), the anthropoid apes, and some rodents. The frequent pathological condition of the appendix in man has given rise to the aphorism "that vestigial structures are particularly prone to disease."

There are various structures in the body which, although not vestigial, give evidence of a retrogression. Such a condiion is to be noted in certain of the sense organs. The olfacory organ, for example, which is of the greatest importance to the lower mammals and other classes of the vertebrates, has become very much reduced in man and is represented peripherally only by a small part of the nasal mucous membrane. In correspondence with this the olfactory portion of the brain is also very much reduced.

Other structures showing signs of retrogression are the teeth. This is indicated by the tendency for the teeth and jaws to become smaller and is very evident when these structures in civilized man are compared with those of the primitive races and with fossil man. Additional evidence is to be noted in the occurrence of misplaced and irregular teeth which, in

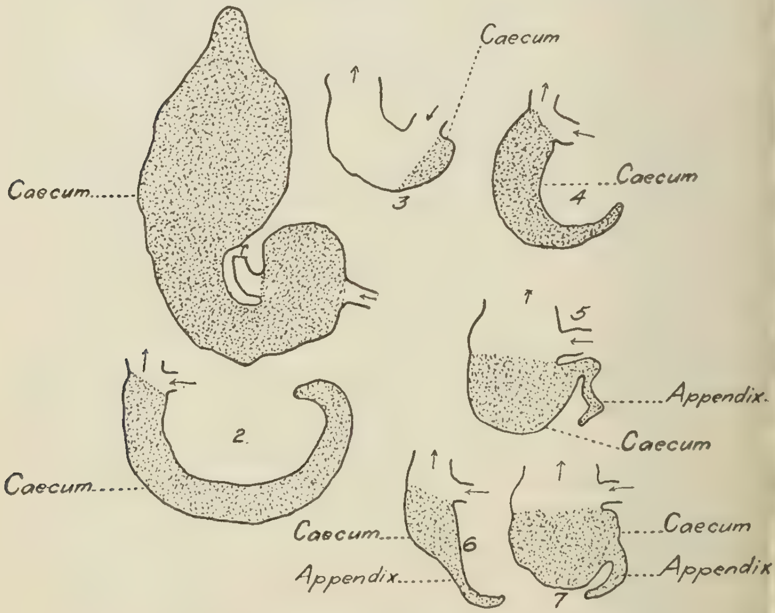


FIG. 55. THE CÆCUM AND VERMIFORM APPENDIX IN VARIOUS MAMMALS

1. Horse; 2. Kangaroo; 3. Cat; 4. Lemur;
5. Orang; 6. Man, fetal; 7. Man, adult.
Redrawn from Stratz, *Naturgeschichte des Menschen.*
By permission of Ferdinand Ecke.

eneral, signify that the jaw is too small. Likewise the fact
at the third molars and lateral incisors are variable in de-
elopment and frequently fail to appear indicates a tendency
a reduction in the number of the teeth. A comparison of
an's dentition with that of a typical mammal having forty-
ur teeth, shows that man has probably already lost twelve
eth during his long period of evolution. The projecting chin
hich man alone of all animals possesses is the result of the
rinkage of the tooth-containing part of the jaw. This can
well illustrated by a comparison of the fossil jaw of the
eidelberg or Neandertal man with that of modern man.
ooth decay also is not found so extensively in the primitive
ces as in the civilized and is apparently absent in the fossil
ces, with the notable exception of the Rhodesian man recently
und in the Broken Hill mine. It is clear that the usual
ophylaxis against tooth decay is merely temporizing with
e real problem. Since the present civilization apparently
rries a distinct threat to the teeth, a radical change in diet
d habits is necessary to preserve them. We are waiting
r our nutrition experts to inform us what these changes
ould be.

ANATOMICAL VARIATIONS

Finally, further evidence as to the ancestral history of man
n be obtained from a study of structural variations. No
o people are exactly alike in bones, muscles, or vessels, and
en the nerves, the least variable structures in the body, show
fferences. Some of these variations are probably fortuitous,
hers are to be considered as a reversion to an ancestral form,
d still others progressive.

Ordinarily man has twelve pairs of ribs but occasionally a
irteenth rib appears. This is known as a cervical rib and is
cated in the neck just above the thorax. It is generally
duced in length but may be long enough to reach the sternum.

It may be that at some time in man's ancestral history this rib regularly existed but now it occurs only occasionally as a reversion to an ancestral type. Its disappearance may perhaps be associated with the assumption of the upright gait, with the resulting dragging down of the viscera by gravity. A tendency to the loss of more ribs is seen occasionally in the partial deficiency of the first rib and in the absence of the twelfth.

Rarely a fourth molar tooth occurs in man, who regularly has only three. Some of the lower mammals have four such teeth. It is possible that the fourth molar in man, when it appears, is a reversion to the former condition. This tooth is more likely to occur in the primitive races and presumably occurred still more frequently in those prehistoric races which are known only by their fossil bones.

In about four per cent of persons a small muscle exists in th front of the thorax, parallel with the sternum, known as th *sternalis*. Anatomists have been much puzzled for an explanation of the occasional presence of this muscle. One theory i that it is part of the pectoral muscle which in some unknow way has become twisted through ninety degrees. That thi may sometimes be the proper explanation is indicated by it receiving a branch of the same nerve which supplies the pe toral muscle. A second theory is that the *sternalis* is a recu rence of part of the subtegumentary muscle which moves th skin, and which is still present in many mammals but has bee largely lost in man. A third explanation is as follows: in th amphibians a longitudinal muscle runs from the pelvis alon the front of the entire body. Although the abdominal part o this is present in man as the *rectus* muscle, the thoracic part absent, having been crowded out of existence, we believe, b the enlargement of the pectoral muscles following the i creased use of the upper extremities for prehension. Som authorities hold that the *sternalis*, when present, is the thorac portion of the *rectus*. An occasional nerve supply from th ntercostals favors this explanation and indicates the possible eversionary character of this muscle.

On the inner side of the lower end of the humerus in the ore limb of man there is occasionally an opening, known as he supracondylar foramen, which is regularly found in some f the lower animals, such as the cat, transmitting a large erve. The occasional appearance of this foramen in man is elieved to be a reversion.

At an early period of prenatal life a pointed projection of he vertebral column as a tail (Fig. 52) is quite evident. uring later development this projection is gradually incor-orated within the body so that the terminal part of the verte-

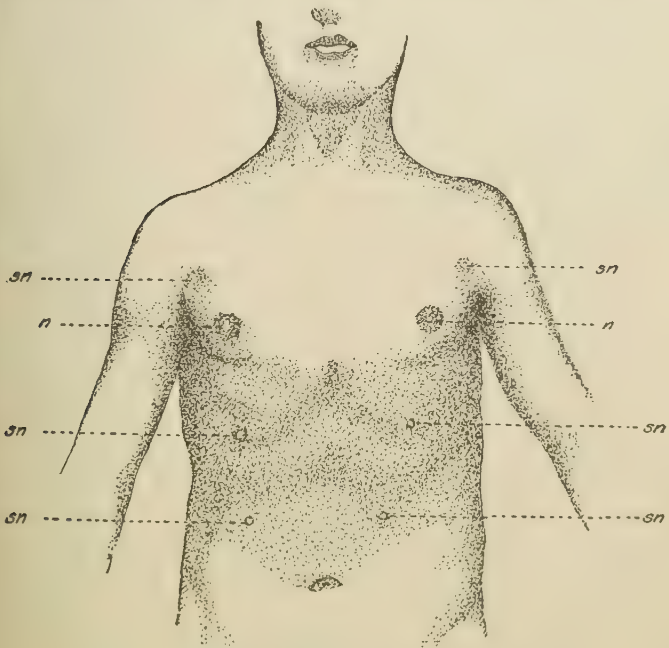


Fig. 56. SUPERNUMERARY NIPPLES OF MAN
n, normal nipple; sn, supernumerary nipple.
Redrawn from Wiedersheim, after Ammon.

bral column, the coccyx, which represents the tail vertebræ of the lower animals, no longer projects. Very rare cases are known in which the coccyx has remained elongated and projecting in man, thus constituting a true tail. In the anthropoid apes this region is even more reduced than in man.

Small supernumerary mammary glands (Fig. 56), which are not infrequently found in man, are reversionary structures. It is found that in early embryonic life, two rows of mammary glands begin to develop but, unlike the case of the lower mammals, all except two of these glands disappear. At the sixth month of prenatal life, the body is almost entirely covered with fine hair, called the lanugo. This is largely shed before birth, but, in some cases, it may persist and develop in the adult to form a complete hairy covering for the body, which seems to be a reversion to man's ancestral hairy condition such as persists in the anthropoid apes.

Thus man's close kinship with the anthropoid apes is strongly suggested not only by the fossil forms but also by his natural history. Furthermore, a 'blood relationship' is indicated both by the susceptibility of the apes to human diseases and by their reaction to various blood tests, developed in the past few years, which render it possible to distinguish between human blood and the blood of all other animals except the anthropoid apes. It is pretty well agreed that the anthropoid apes and man came from a common ancestor, and he in turn from some primitive, broad-nosed ape. Some believe that the mammals were evolved from a primitive reptilian form. Others say they came from the amphibians, which in turn evolved from a fish form, the latter from an invertebrate, and so on down to the protozoa. Evolution must likewise assume that under some favorable condition the earliest living forms were evolved from the inorganic world. Whether such a process is going on at present no one knows. However, the facts of man's development, structure, and variations, which have been given above, certainly can be best explained on the basis of man's descent from lower forms, and human fossils, as far as they go, as is clearly shown in the previous chapter, definitely lead back toward a form from which both apes and man may have descended.

CHAPTER VII

THE EVOLUTION OF THE NERVOUS SYSTEM OF MAN

GEORGE HOWARD PARKER
PROFESSOR OF ZOÖLOGY, HARVARD UNIVERSITY

The body of man, like that of the other higher animals, carries a full complement of organs. These organs are usually arranged by anatomists under some ten heads, the so-called organ systems, and are familiar to you as the skeleton, the muscular system, the circulatory system, the nervous system, and so forth. Although physicians have been telling us that we normally live so long as our blood vessels last, it is nevertheless true that our daily life is dependent not upon a single system of organs strictly but upon the interaction of all the systems that we possess. No one system can be eliminated without serious consequences. True we may have our tonsils taken out, our appendix removed, we may lose an arm or a leg, a kidney, or even a lung, but no one will give up with impunity both kidneys, or both lungs, or shed his whole digestive tract. Death would be the inevitable and immediate result. Our systems of organs are so interrelated that they form a unified whole which justifies the biological conception of an organic individual. The integrity and continued existence of such an individual is dependent upon the presence of at least the essential members of each system. Thus the organism as a whole, to use a current expression, is more than an assemblage of parts; it is an integrated unit.

The Nervous System and Personality

Yet when we examine our systems of organs, we find them uite differently related to our daily activities; the musician rains his ear, the artist his eye, and the athlete his muscles. n this way each one develops a certain individuality or what commonly spoken of as a personality, to use that term in its iore modern connotation. In this sense personality implies n outline of the self, a *résumé* of that body of characteristics iat makes up an individual in contradistinction to other indi- iduals. Personality has commonly been regarded as an attri- ute of the body as a whole and yet when it is closely scruti- ized, it is seen to depend chiefly, if not entirely, upon our ervous organization.

That personality has its seat in the nervous system is in the iain a relatively modern view. The ancients for the most art believed that it permeated the whole human frame, and iey located what may be called the attributes of personality i the most diverse parts. Thus Aristotle declared the heart be the *sensorium commune* of the body and, though he was n unusually acute observer, he was unable to make out any ervous function whatever for the brain. Galen believed the rain to be the seat of the rational soul, but apparently he also ccepted the popular belief that the heart was the seat of ourage and anger, and the liver that of love. Views of this ind were the prevailing opinions among the ancient writers nd show that what we regard nowadays as personality had or them a most broad and general relation to the body as a hole.

Vesalius, the great anatomist of the sixteenth century, may e regarded as the founder of the modern belief that per- onality is of strictly nervous origin. In dealing with the ervous system he declares that just as the heart is concerned ith the vital spirit, and the liver with the natural spirit, so is the brain with the animal spirit. By the animal spirit, as the context shows, he meant the capacity to think, to remember, to reason, and to imagine. All these functions, however, are functions of the brain, and that body of reactions, instincts, and habits that characterizes each individual whereby he may be described as honest or dishonest, cheery or somber, kindly or malevolent, are from this standpoint products of the nervous system. Although this view has been again and again assailed, it has maintained itself to the present time and bids well to remain one of the fundamental facts of biological knowledge.

Yet to the man on the street personality and all that pertains thereto remains much as in pre-Vesalian days, a vague general characteristic of the body as a whole and not a feature of one system of its organs. To attempt to persuade him otherwise is more likely to arouse his suspicions than to advance his knowledge. This is particularly true of so simple a matter as sensation. When you prick your skin with a pin nothing seems more natural than to locate the sensation of pain where the pin abraded the skin and yet we know that the sensation of pain is in the cerebral cortex of the brain and not in the skin. The evidence that this sensation is resident in the cortex comes from several sources. First, it is known that if a nerve is cut, the part of the body supplied by that nerve loses sensibility. When a nerve going to a part of the hand is accidentally severed, a pin may be thrust into that part without producing the least sensation whatever, showing that the hand in itself is not endowed with pain. Not until the restoration of the nerve months after the accident does the sensation of the afflicted part return. Not only are there circumstances under which a part may be present though without sensation, but there may be sensations without the presence of any part. This condition is well seen in the so-called phantasmal extremies. Persons who have recently lost an arm or a leg often uffer from very intense pains apparently in the missing part. o real are these sensations and so definitely do they seem to e located in the lost member that it is often difficult to peruade the patient that the pains are not connected with the lost art and that some attention to that part is needed. Yet the urgeon knows perfectly well that these sensations are caused y small tumors on the cut ends of the nerves that formerly vent to the lost extremity. On removing these tumors the ensations disappear. Both these lines of evidence show that ainful sensations though commonly referred to the skin are eally not situated there. They are functions of a more leeply located part. When the central end of the system in he cerebral cortex suffers destruction either by disease or accident, sensation disappears absolutely and completely, a condition that shows that the real seat of this phenomenon is not in he peripheral parts of the body, as commonly assumed, but in deep portion of the central nervous system.

This is but one example of many that go to show that peronality, not only from its sensational side but from all other spects of its nature, is a function of the nervous system. It s not a quality that penetrates the human frame as a whole. Yet notwithstanding the correctness of the modern view as o the seat of personality, the ancient idea of its diffuse nature ppears in many of our daily habits and permeates our language. It would be impossible to replace successfully the eart on the February valentine by the true organ of affection, he cerebral cortex, even though the convolutions of the cortex night be shown to afford a much more subtile means of sendng the hidden message than the smooth surface of the heart. Human nature clings to the past and the discarded theories of he physicians of antiquity hold their place with tenacity in the anguage of to-day.

The Nervous System of Man and Other Higher Animals

The nervous system of man is without doubt one of the most intricate structures in the animal kingdom. It is composed of a most complicated mechanism of end-stations and of intercommunicating lines which far outruns in intricacy the telephone system of such a place as Chicago or New York. It is made of nerve cells, or neurones, whose processes, the nerve fibers, stretch like telephone wires for relatively prodigious distances through the body. When these neurones are studied individually they are seen to fall into three classes. One of these classes is composed of elements that reach from the skin and other outlying parts, such as the organs of smell, taste, hearing, and the like, to the central organs. These neurones are called sensory or afferent neurones. Other neurones, commonly called motor or, better, efferent, stretch from the central apparatus to the muscles and other organs activated by the nerves. These form the second class. The third class, the internuncial neurones, connect one part of the central nervous system with another; they consequently lie entirely within the limits of the central organ and may be in accordance with their connections either functionally afferent or efferent. These three classes of neurones make up the whole of the real nervous substance of the human body and collectively they constitute a system by means of which many of the bodily activities are controlled and in which take place such remarkable operations as sensation, memory, volition, and the host of other performances which together constitute personality.

When we survey the organization of the nervous system and its appended parts we find that, though it is made up of neurones, the boundaries of its organs do not conform to the limits of the neurones, but have a topography of their own

hus a whole group of peripheral parts, often the peripheral
ıds of afferent neurones, are concerned with receiving such
nvironmental changes as are likely to excite activity in the
rganism. Thus the eye is receptive for light, the ear for
ound, the organs of touch for changes of pressure and the
ke. These organs, commonly designated as sense organs,
ut more appropriately called receptors, constitute the first
ırge class of parts in the neuromuscular mechanism. The
econd class includes the central apparatus proper, composed
f the central ends of the afferent neurones, the internuncial
eurones, and the central ends of the efferent elements. This is
ıe portion of the system, corresponding to a central telephone
ation, in which the nervous impulses arriving from the re-
eptors are directed toward the appropriate channels of re-
ponse and in which are stored those records of past experi-
nce that modify or otherwise qualify the subsequent responses.
his second portion is represented in man by the brain, and the
pinal cord, and by the sympathetic system and may be desig-
ated from one of its chief functions as the adjustor mecha-
ism. Finally there is to be mentioned the third group of parts,
ot truly nervous themselves, but under the control of the
ervous system, the muscles, the electric organs, the glands,
he luminous organs and the like, all of which enable the
nimal to act in some particular way on the environment.
hese have been appropriately spoken of as effectors and com-
lete the list of necessary parts in the neuromuscular mecha-
ism.

A nervous system composed of the three types of neurones
lready mentioned and organized into receptors, adjustors,
nd effectors is characteristic of most of the higher animals.
t is found not only in the vertebrates from man to the fishes,
ut also in the mollusks, in the arthropods, and in the higher
vorms such as the annelids. Even such a lowly organized
reature as an earthworm has a nervous system developed

upon this plan. The so-called brain of this animal is a smal mass of nervous material lodged in the dorsal part of i anterior end. Connected with this brain is a long segmenta chain of ganglionic enlargements extending along the ventra midline of the worm. These parts collectively constitute th central nervous apparatus, or adjustor, for which the skin i the chief receptor and the muscles the main effectors. I neuronic composition the three types of elements already described are abundantly represented. Afferent neurones reac from the skin of the worm to its central organs from whic efferent neurones pass out to its muscles. Internuncial neurone are also present, but in relatively small numbers as compare with the conditions found, for instance, in the vertebrates Here many parts, like the cerebral hemispheres, to take onl one example, are made exclusively of internuncial neurone whereas in the earthworm there is probably not a single important nerve center that is not entered by sensory neurone or which does not give rise directly to efferent neurones With this difference, however, the neuromuscular mechanism of the earthworm is based on the same principles of construction as those met with in the higher vertebrates including ma himself.

The Nervous Organization of Sea-Anemones

To gain some idea of the evolutionary steps by which suc a nervous system as that just described has been arrived at, i is plainly necessary to examine the types of nervous organization found among the lowest of the multicellular animals. A a good example of these lowly organisms the sea-anemone may be selected. Sea-anemones are sac-like animals attache to rocks or stones, and provided with a single aperture whic leads from the exterior into their large central cavity in whic digestion goes on and from which the undigested residue i scharged to the exterior through the single aperture already entioned which serves thus both as mouth and anus. This erture in almost all sea-anemones is surrounded by one or ore circles of tentacles.

When an expanded sea-anemone is stimulated by being uched or otherwise excited to action, it commonly responds y a quick general contraction, whereby the seawater contained its digestive cavity is discharged through its mouth and the hole volume of the animal is greatly reduced. This general ntraction may be called forth from almost any point on the rface of the animal, showing that the muscles that lie within e walls of the creature and are responsible for the contrac- on, are collectively accessible to nervous impulses from al- ost every point on the surface. This accessibility is insured rough the presence of a nerve-net which spreads throughout e living substance of the animal and which brings its surface to connection with almost its whole musculature. This erve-net nowhere shows a special concentration but extends ather uniformly throughout the body and thus affords an easy ath over which impulses may spread from the surface of the nimal to its musculature. A nervous system of this type is mmonly called a diffuse nervous system as contrasted with a ntralized one and is characterized by the absence of a cen- al organ, or adjustor, through which all impulses must pass n their way from the receptors to the effectors.

The characteristics by which a diffuse nervous system may e distinguished from a centralized one are well shown in a umber of activities exhibited by sea-anemones. When small ragments of meat or other bits of food are placed on the entacles of a sea-anemone, these organs wind around the bits f food and, by bending in the appropriate direction, deliver hem to the mouth. If, now, a distending tentacle on a quiet nd expanded sea-anemone is suddenly seized at its base by orceps, cut off and held in position so that its original relations to the animal as a whole can be kept clearly in mind, the tentacle will still be found to respond to food brought in contact with it and will eventually turn toward that side which was originally toward the mouth. Thus the tentacle has within itself a complete neuromuscular mechanism for its own responses and it is unnecessary that it should be connected with any general nervous center in order to carry out its characteristic movements. Its share of the diffuse nervous system is sufficient for its own needs. How different this type of organization is as compared with the centralized type is seen when we contrast the activity of the tentacle with that of the leg of a dog or the claw of a lobster when severed from the animal's body. These parts when thus cut off are quite incapable of coördinated movement and show no evidence whatever of the type of response that characterizes them as a part of the whole organism.

Another activity of the sea-anemone that illustrates the nature of the diffuse nervous system is creeping. This operation is accomplished by the so-called pedal disc, that portion of the animal by which it attaches itself to the substrate. By means of muscular waves that pass across this disc the sea-anemone may creep slowly like a snail from spot to spot. If a sea-anemone is cut crosswise in two and the upper half of the animal carrying the mouth and tentacles is thus removed, the lower half with the pedal disc intact will pucker up the wounded surface and soon creep about with as much success as the whole animal did. Here again the part concerned carries within its own bounds a neuromuscular mechanism complete for its needs.

Again if a sea-anemone is fed from one side of its mouth, it will take in by means of the tentacles on that side one fragment of food after another. If, now, bits of meat be alternated with bits of filter paper soaked in meat juice, the two materials will be accepted indiscriminately for some eight or n trials after which only the meat will be taken and the filter aper will be discharged into the seawater without being rought to the mouth. If, after having developed this state f affairs on one side of the mouth, the experiment is now ansferred to the opposite side, both the filter paper and the eat will again be taken in till this side has also been brought a state of discriminating. Thus the experience of one part f the animal has no perceptible influence on another in the nse that there is no common nervous center where the experi-nce of a given part may be put to the service of the rest. It is s though we had to burn each finger in turn before we discover at fire is bad for the hand. These examples bring into rong contrast the types of reaction characteristic of the igher and the lower multicellular animals and serve to illus-ate the difference between the centralized and the diffuse ervous system.

In a diffuse nervous system, such as that possessed by a sea-nemone, the external surfaces of the animal serve as recep-ors and these communicate directly with the subjacent muscu-ture. The nerve-net serves to spread the impulses throughout e body but without involving any central organ. Thus the a-anemone may be said to possess receptors and effectors ithout an adjustor or central nervous organ properly so alled. This central organ is, therefore, a feature of the igher animals and in comparison with receptors and effectors must be looked upon as a more recent evolutionary acquisi-on. Our sense organs did not develop in consequence of a ntral nervous system but our central nervous organs devel-ped because our very early ancestors had already acquired ceptors and muscles.

If lowly organized animals, such as sea-anemones, possess othing worthy of the name of a central nervous organ, it llows that their so-called sense organs must differ consider-bly in function from those of the higher animals. In highly differentiated types the sense organs, the eye, the ear, th organs of touch, of taste, and of smell, are concerned with supplying the central apparatus with those elements out o which the intellectual life is built. This function must be entirely superfluous in such an animal as a sea-anemone where no central organ exists. Here the sense organs are not concerned with sensations; they merely excite muscles to action a function which they also exercise in the higher animals. They are receptors for a multitude of external changes and when thus excited they serve as triggers, so to speak, to se off the subjacent muscles. Since they are not concerned with sensations they are more appropriately designated as receptors than as sense organs and hence the term receptor, which is th more inclusive of the two, is the better one to employ. Sea-anemones, therefore, represent a more primitive type of neuromuscular mechanism than the higher animals do, one in which of the three organs, receptor, adjustor, and effector, only th first and last are present, the adjustor, or central organ, being a later acquisition.

SPONGES

If receptors and effectors were developed before adjustors it is natural to ask whether of these two parts one preceded th other or did they both evolve simultaneously? Among th multicellular animals lower than the sea-anemones, the sponges throw light on this question. A single sponge is a goblet-shaped or finger-shaped animal attached to the sea-bed. Its outer surface is covered with pores which lead into a system o canals provided with lash-cells by which the water is moved through the canals to a large space in the middle of the spong from which this fluid escapes by a conspicuous opening at th unattached end. From the current of water thus passing through the sponge the animal extracts its nourishment and th roduction and control of this current is one of its essential ctivities.

Many sponges, like the ordinary bath sponge, are colonial nimals and consist of a number of sponge individuals more or ess fused together. In the bath sponge, which in its commerial form is represented merely by its horny skeleton, the numer of individuals can be judged by the number of very large penings that penetrate from the outside to its interior. These re usually four, five, or more in number and represent the utlets for the water currents in the living sponge. In quite number of the colonial sponges the component individuals re much more separated than in the bath sponge and rise rom a common base as so many separate fingers. Such ngered sponges are very convenient for study and are comnonly of such a size as to admit of easy experimental treatnent.

Sponges are for the most part extremely inert and aside rom a slight contraction and consequent bending of the body s a whole they show very few activities except the opening nd closing of their pores and other apertures. In this way ponges control their water currents and they accomplish his partly by the formation of protoplasmic membranes by hich the pores are closed and partly by the action of rings of mple muscle cells that surround the pores, especially the outet openings.

The control of a given outlet cannot be accomplished from n adjacent finger nor can it be brought about by stimulating he finger at the end of which the outlet lies except when the timulus is directed to the immediate neighborhood of the utlet itself. In fact there is not only no experimental evience to show that one finger is connected nervously with nother, but there is no reason to suppose that parts of the ame finger are thus connected. In other words, nervous transmission, such as is abundantly seen in sea-anemones, seems to be completely absent from sponges. When this fact is coupled with the inability of histologists to discover any trace of nervous tissue in sponges, it seems safe to conclude that these animals are devoid of nervous elements and that their muscles are set in operation by direct stimulation rather than by anything that may be described as a nervous impulse. From this standpoint, therefore, sponges may be regarded as animals provided with muscles but devoid of nervous tissue They possess effectors but no receptors and their condition suggests that in the evolution of the neuromuscular mechanism, muscle appeared first and nervous tissue later, developing probably in close proximity to the previously formed muscle as a device for exciting the muscle to action.

If this conclusion is true, the evolution of the neuromuscula system must have begun with the appearance of muscle as an independent effector, after which receptors, or nervous elements to serve as triggers for setting off the muscles, were added. Finally, between the receptors and the effectors a central nervous organ, or adjustor, grew up as the third element and thus completed the neuromuscular system as exemplified in the higher animals. So important has this central orga become in the life of these animals that we scarcely reali that it is the latest addition to our nervous equipment and ye such seems to be the case. In its first appearance it must hav been chiefly an organ of transmission and intercommunicatio a specialized outgrowth of the more diffuse nerve-net. Late it doubtless took on the function of modifying the animal' responses in relation to its past and thus became a storehous of experience and the seat of the intellectual life. As such has reached its highest point of development in the vertebrates where as the brain of man it is without doubt the mos remarkable structure ever evolved.

The Nervous System in Vertebrates

The central nervous organ of the vertebrate, using this term n the most limited sense, consists of the spinal cord and the rain. The spinal cord throughout the vertebrate series is a elatively uniform structure, but the brain exhibits a strikingly rogressive development. This is seen especially in two of its arts, the cerebellum and the cerebral hemispheres. Both, but articularly the cerebral hemispheres, grow immensely in size nd complication as we proceed from the fishes to man. In he lower vertebrates the cerebral hemispheres are concerned lmost entirely with the sense of smell and their cortex, or outer overing, is spoken of as the olfactory cortex, or archipallium. n the mammals, however, the hemispheres have reflected pon them, in addition to olfaction, practically all the sensory ctivities of the body as well as the mechanism for the volun-ary control of the musculature. These added parts constitute he neopallium which shoves the olfactory archipallium into he background. Thus the neopallium comes to be the great entral organ of the higher animals. It receives almost the vhole of the sensory inflow; it stores the impressions of the ast; and from it emanate those impulses that excite what we all our volitions.

It is a remarkable fact that in man the cerebral cortex con-ists of layers of nerve cells so regularly arranged that a rough stimate of their number may be made. This is believed to be pproximately 9,200,000,000. This prodigious number of ells is estimated to weigh a little over thirteen grams and to ccupy the space of less than a cubic inch. When it is re-nembered that every human being develops from an egg cell f approximately one fifth of a millimeter in diameter and that his cell begins growth by dividing into two, and these two each nto two thus making four, and then into eight, sixteen, thirty-wo, and so forth, it will be seen what a stupendous process development is even from the standpoint of simple numbers, for from this one egg cell by division must come not simply the nine billion and more cells of the cortex, but all the other countless billions of cells that go to make up the rest of the body. Nor is this process of cell multiplication, prodigious as its results show it to be, the only remarkable feature in development, for it is also equally striking that when the requisite number of cells have been produced, the operation of cell division stops. At least this is true of the cortex, for here, as in a few other parts of the body, the neurones change very little in number after birth. The brain cells with which the babe is born last for the most part without renewal through mature life to old age and death. What brings the operation of cell multiplication to an end at the appropriate moment is as little understood by embryologists as is the exciting cause of the initial increase.

When it is recalled that the 9,200,000,000 cells in the human cerebral cortex are the nervous elements of this organ and that they collectively constitute rather less than a cubic inch of protoplasm, it seems almost incredible that they should serve us as they do. They are the materials whose activities represent all human mental states, sensations, memories, volitions, emotions, affections, the highest flights of poetry, the most profound thoughts of philosophy, the most far-reaching theories of science, and, when their action goes astray, the ravings of insanity. It is this small amount of protoplasm in each of us that our whole educational system is concerned with training and that serves us through a lifetime in the growth of personality.

THE NERVOUS SYSTEM AND SEX

The great importance of the nervous system for all that pertains to the higher life of man cannot be denied and yet this ystem after all is only one of our numerous systems of organs and lies embedded with the rest as part and parcel of our bodies. Notwithstanding its unique character, the nervous system is profoundly influenced by its organic environment and reflects in much that comes from it the characteristics of the body in which it lies. This is nowhere more clearly seen than n the effects which hormones have upon it. Hormones, as you already know, are substances produced in the bodies of the higher animals by the ductless glands, or endocrine organs as they are now called, and circulated by the blood. They are powerful activators for many bodily reactions and are of first mportance in many organic activities. Certain hormones have a profound effect upon the nervous system and consequently upon personality. In this respect they are like the supposed humors of the physicians of antiquity. These humors were believed to be four in number, blood, phlegm, yellow bile, and black bile, and an excess of any one of these gave a corresponding temperament, sanguinary, phlegmatic, choleric, or melancholic as the case might be. This idea of the humors is really a forerunner of the well-established theory of the hormones, which, however, not only has to do with temperament but with many other functions of the body. That materials introduced into the circulation have a profound influence on our moods and other mental states is well known and is the basis of the use and abuse of many substances, such as narcotics, alcohol, coffee, tea, tobacco, and so forth. It is, however, only within the last few years that the immense importance of hormones in relation to the nervous system has begun to be seen. The hormones concerned are those that have to do with the sexual traits.

The great majority of animals are either male or female and when we seek for a definition of these states we are driven in the end to make it turn upon the kind of reproductive cells that the individual produces. Males produce sperm cells;

females egg cells. These are the primary sexual characteristics. But the sex of the great majority of higher animals can also be determined by many features other than those of the kind of reproductive cell discharged. Thus in man the male as compared with the female is usually larger in stature and more robust, has hair upon the face, a deeper voice, and many other features all of which go to mark the sex as clearly and as indubitably as the primary sexual character itself. These more superficial and obvious distinctions are spoken of collectively as the secondary sexual characters and serve, as has just been intimated, with almost perfect certainty as an indication of sex. If, however, there is any ambiguity in this respect, the final resort in a decision is always to the primary sexual characters, the kind of reproductive cells produced by the given individual.

For a long time much interest has been expressed as to the way in which the secondary sexual characters arise and it is from this standpoint that hormones have come into much prominence. Very remarkable experiments in this direction have been recently carried out by Steinach on guinea pigs and rats. The original object of this line of work was to ascertain the influence of the sexual glands on the secondary sexual characters, but the outcome of it was the discovery of a means of influencing in a most profound way the sexual life of an individual, in fact, so far as secondary sexual characters are concerned, of converting a male into a female and vice versa.

Steinach removed the male reproductive glands, the testes, from young guinea pigs and, after they had recovered from this operation, he implanted in their bodies by means of a second operation the female gland or ovary from a young female. The animal destined by nature to be a male but thus harboring within its body the opposite sex gland was allowed to mature, whereat a most remarkable transformation was observed. It developed the bodily proportions of the female in skeleton, hair coat, and other particulars, its mammary glands enlarged and even gave milk, but what is perhaps more remarkable was that its whole nervous constitution gradually assumed the female rôle. It became rather timid and retreating, mothered the young of other females and in practically all respects exhibited the traits of the female of its kind. Organically it displayed practically the full range of secondary female characteristics though it was an animal destined by nature to have been a male.

Steinach also undertook the conversion of females into males and though this from the operative standpoint proved to be a more difficult problem, in that testes had to be repeatedly introduced, he nevertheless also succeeded in this endeavor and individuals were produced that though destined by nature to be female had the physical and psychical traits of males. Such individuals were aggressive and quarrelsome, and attempted, though ineffectually of course, to copulate with females.

Thus the presence of a particular sex gland during adolescence seems to be the necessary factor in determining the type of secondary sexual characters that a given individual will show. When the sex glands that had been transplanted in these experiments and that had sojourned in their new habitation for a considerable time were studied histologically, they were found to be considerably modified. The sexual cells proper had often largely disappeared and the cells that filled the spaces between the groups of sex cells, the so-called interstitial cells, had often greatly increased. It is these cells rather than the sex cells which produce the hormones that determine the secondary sexual characters, and the sex glands must, therefore, be looked upon as double in nature. They produce, first, the sexual elements, the sperm cells or the egg cells, and secondly, from another source, the hormones necessary for the development of the secondary sexual characters. They are at once sex glands and puberty glands.

When the full import of these experiments is clearly recognized, it must be admitted at once that the sex glands not only control such secondary sexual characteristics as are of a physical nature, such as bodily proportions and the like, but also those more subtile features, the reactions, responses, and instincts, which are equally significant in defining a given sex. These features collectively have their origin in the nervous system and since they are now known, from the experiments o Steinach, to depend for their development upon the sex glands, it follows that the nervous system of an immature animal must be looked upon as neither male nor female but indifferent and yet capable of developing in either one or the other directio in accordance with its organic environment.

That the conclusions to be drawn from Steinach's experiment apply with full force to human beings is now commonl admitted. The striking influence of the sex glands on personality as well as on the more physical aspects of the individua is well known to every surgeon and is a cardinal point in hi practice. Yet the relation of this simple fact to human societ often goes unheeded. Few elements lie deeper in the natur of man than sex. As the center around which the family is built up, it initiates the first step in the structure of society From this soil have sprung the affections, chivalry, the poetr of love, and all that vast array of literary and artistic accomplishment that has as its theme man and woman. And ye when the physical background of this immense pageant is sought for, it appears to depend upon the action of the interstitial secretions of the sex glands on plastic nervous organs It is this plasticity that is both novel and important, for it ma have far-reaching consequences in the reconstruction of society Through it personality may be profoundly affected, abnorma states may be reached and corrected, and fundamental regenerations accomplished. As an avenue of entrance it lead to a most important field for the psychiatrist and the soci eformer. Thus the hormones, to return to our original thesis, llustrate how profoundly the nervous system is under the inluence of its immediate organic environment.

THE NERVOUS SYSTEM AND ORGANIZATION

If, now, we picture to ourselves the evolution of the nervous system of man, we must imagine the formation of the chemical elements from the electrons of the stellar laboratories, the combination of certain of these elements into organic aggregates and the formation of unicellular organisms, the development of multicellular types in whose organization muscles appear, then receptors, and finally adjustors or central nervous organs culminating in the brain of man.

Such a series forms, superficially, a seemingly natural and smooth sequence and yet when it is examined closely, it proves to be a succession of breaks and contradictions. The carbon, hydrogen, oxygen, nitrogen, and other elements of our bodies act in a radically different way in the hands of the chemist from what they do as an organized part of our nervous protoplasm. The invariable nature of the chemical reaction is in strong contrast with the fluctuating uncertainty of volitional activity. True, on repeating what are intended to be exactly the same processes, the chemist never gets exactly the same results, but he knows that the slight differences he meets with in his work are errors of manipulation and observation and not evidences of wilfulness or disobedience on the part of the material he deals with. Yet the activities of these same chemical elements when organized into the children of his family are regarded in a very different light and under the head of personality he subjects them to censure and approval with the view of lasting change and improvement. How profoundly different is the conception of the activities of the isolated elements of our bodies and of these same elements organized into parts of ourselves! No one now entertains seriously the view once put forward by Haeckel in the heyday of the evolutionary movement that since human beings have souls every atom of their bodies must have part of such a soul. The circumscribed nature of ordinary chemical action and the freedom of human volition, notwithstanding its elemental background, are two different things.

If the peculiarities of volitional action are not to be discovered in the chemical elements that make up the substance in which it occurs, they must be ascribed to the organization of this substance, that is, to the way in which the elements of this substance are put together and interact amongst themselves. From this standpoint certain chemical elements organized as nervous protoplasm have a greater degree of freedom in their action than when the same elements are organized in the form of lifeless molecules. This condition may be illustrated by a simple mathematical relation. The ordinary and invariable type of chemical reaction might be likened to what would take place in a mathematical world made of blocks of fives to which we put the question, What constitutes ten? To this there is only one answer, namely, two blocks of five. The type of reaction that is possible in nervous protoplasm is like that in a world made of the digits to which the answers as to what make ten may be nine and one, or three and seven, or any other of numerous combinations all equally true. This world has in it a degree of freedom comparable to that in nervous protoplasm as compared with the limitations of the ordinary chemical reaction. From this standpoint, then, nervous protoplasm, and probably most other protoplasm, when considered from the point of view of its chemical activities has a greater degree of freedom than that seen in the ordinary chemical reaction and in this characteristic is to be found the possibility of all volitional performance. That the properties and activities of materials change with changes in organization as well known to the student of the lifeless phases of nature s to those who concern themselves with the so-called organsms. The qualities and activities of water are no more novel r different from those of its component elements, hydrogen nd oxygen, than are the qualities and activities of nervous rotoplasm as compared with the organic molecules that make up. Water is organized hydrogen and oxygen and in conequence of its peculiar type of organization it exhibits proprties quite unlike those of its constituent elements. Thus vater, like protoplasm, differs from its elements in conseuence of its organization.

It is sometimes assumed that man is absolutely untrammeled nd free and that his inner life is without restriction, but such s not the case. A good example of how we are held in abeynce is seen in our mental furniture. This consists of elements, ur sensations, that reach us from the outer world through our ense organs. These elements come to us from the environnent and from nowhere else. We never invent them nor in ny other way develop them within ourselves. The mind is trictly limited to what in this respect is supplied it from its xterior. What may be done by way of freedom and origiality is to set these elements in novel and unusual combinaions and it is in this way that the highly imaginative and erhaps the insane mind works. But in all instances the elenents themselves are those of the primitive sensations and to uch we appear to be absolutely limited.

Not only is the mind thus limited in its materials, but its rocesses often show striking restrictions. This is illustrated y the magician's receipt for turning stone into gold. Put a lean stone into a pot of boiling water and watch it ten minutes luring which time, if you do not once think "hippopotamus," he stone will turn into gold. Needless to say that no one by his means has ever enriched himself. The mind of man even n working toward its desires is never absolutely free, but is subject to restrictions which continually recall the material background on which it rests.

In the evolution of the nervous system of man as presented in this brief outline we see a succession of steps rather than a gradual ascent and at each step a fundamental change suddenly appears, mutation-like in its character, to borrow a term from the geneticists. Each step is a new phase in organization, but not necessarily a change in the kind of elementary materials involved, and with these changes in organization come changes in the degrees of freedom of reaction which enable us to bridge over the gulf that lies between the relatively circumscribed activity in ordinary chemical operations and the greater freedom seen in the voluntary and responsible acts of human beings. Something of this view of the nature and the possibilities of living protoplasm has been put forward by Haldane under the name of organicism, but with perhaps less reliance on the material side of the problem than has been suggested in this lecture. Yet interesting and important as it is to push, to the extreme, speculation as to the relation of our mental life to the materials of our body, it nevertheless must be remembered that, with all our progress, we are still not far from the position described by Vesalius in 1543 when he wrote, "How the brain performs its functions in imagination, in reasoning, in thinking, and in memory, I can form no opinion whatever."

CHAPTER VIII

THE EVOLUTION OF INTELLIGENCE

JAMES ROWLAND ANGELL

PRESIDENT OF YALE UNIVERSITY

It may be assumed without argument that evolution has tually occurred within the field of intelligence, as it has ithin the field of organic structure, and I shall proceed at ce to examine the major features of the process. It will be nvenient to distinguish in such an analysis between the de- lopment of intelligence in animals and the corresponding velopment in man. This distinction is not for a moment tended to postulate any fundamental difference between hu- an and animal intelligence, for this is one of the questions hich can only be confidently answered, if at all, after adequate amination of the available data. It is simply a device for pediting access to two great groups of facts which present rtain practical distinctions.

In the field of cosmic and stellar evolution, we have such cts as are disclosed to us through telescopic and spectro- opic examination of the heavenly bodies, with their convinc- g indications of evolutionary processes extending over un- aginable epochs of time and over equally abysmal areas of ace. In the case of the crust of our own earth, geology milarly brings to our knowledge evidence of slow, age-long anges, as a result of which the present superficial character- tics of the earth's surface have been produced, together with s climatic and other peculiarities. Again, there is convincing evidence of change and development, of rise and fall, in th tide of animal life, in its geographical range, in its anatomica organization, and in its adjustability to the major features environment. One of the lectures in this series has in particular been devoted to evidence of this character as it applies t the changes brought about in the nervous system of variou forms of animal life. The development of man himself and o the society within which he lives has also been passed in revie and convincing demonstration has been offered of the extensiv changes which have, throughout the ages, come to pass in both Evolution having been thus convincingly exhibited in a numbe of important fields, it behooves us, in discussing the presen problem, to secure impressions as clear as possible of the character of the evidence upon which we are to base our inference and conclusions regarding the development of intelligence.

Animal Intelligence

In the case of animal life, the only available information i to be gained by the direct observation of animal behavior a that is found among the creatures surviving in our age of th world. Whether there may have been creatures in the pas possessing forms of intelligence substantially different fro that of any animals now living can neither be denied nor asserted with absolute confidence. But such evidence as we hav is at least all against the inference that animals superior t those now living have ever been developed. So great is th similarity of existing forms to such extinct forms as are know to us, that it seems highly improbable there should have occurred developments of intelligence widely different from thos represented in the animal life of to-day. This inference to be sure, rests upon the hypothesis which most scientists regard as conclusively established, to wit, that intelligence i

sentially a function of the nervous system and that its char-
teristics vary with the development of the latter.

Turning, therefore, for our clew to the behavior of living
ganisms, we find this ranging all the way from the very simple
ries of movements executed by the unicellular organisms like
nœba, which is quite devoid of a specialized nervous system,
to the complicated behavior of the primates and the phe-
menal intellectual achievements of man himself. At once
e are confronted with a distinction which, much transformed
modern times, goes back to the period of the earliest specu-
tions upon mind and behavior. All the early writers known
us stress the distinction between instinct and reason, ac-
editing to the animals instinctive behavior of a far more
ighly developed type than that disclosed in the behavior of
an, and assigning to man powers of reasoning either wholly
r largely denied to animals. Modern scientific analysis has
een disposed greatly to qualify the rigidity of this distinction.
Ian certainly has a very definite equipment of instincts and
me of the operations of animals contain in them the begin-
ings at least of rational conduct.

Broadly speaking, actions are designated intelligent when
ey disclose the ability to adjust quickly and successfully to
ew and variable conditions. They are judged unintelligent
r mechanical when the same action is elicited again and again
egardless of changes in the situation which calls it forth, or
f the possibly disastrous nature of the reaction itself. From
is point of view, the great group of actions, known as tro-
isms, must be regarded as non-intelligent, even though they
ay at times benefit their possessors. Here, for example, is a
roup of organisms which at once seek the darkest corner of
ny area within which they are confined. Here is another
roup which seeks the lightest place. Again, here is a group
hich, if possible, takes up a position where the body may
ress, or be pressed upon by, surrounding objects. In the case

of such organisms these tropistic tendencies are ordinarily responded to no matter how untoward the consequences. The moth seeking the flame is a common exemplar of this kind of reaction. And the biologically undesirable consequences are plainly exhibited in the demise of the performer.

The group of reactions called reflex exhibit a similar organic invariability which, while generally beneficial, is not infrequently disadvantageous. In the human being sneezing, coughing, weeping, are familiar examples of actions of this character. They are largely outside the range of voluntary control and the more extreme forms, such as those of digestion, are completely independent of such direct control.

Instincts shade off into reflex and tropistic reactions by gradations, which makes it difficult without being arbitrary to draw any hard and fast lines; but they are in the higher organisms much less rigid and fixed than the tropisms and reflexes and they are more complicated than the latter because they involve a series of muscular movements, instead of the single movement to which we apply the term reflex.

All this group of activities, however, have in common their hereditary and innate character. No one of the group is ever in any proper sense learned or acquired. They are executed either at birth, or at some later stage of the creature's development, with a high degree of perfection and in the lower animals they are generally quite rigid and devoid of any suggestion of intelligent adaptation. They certainly represent hereditary pathways through the nervous system over which stimulations travel to the muscles and glands. In the higher animals, the instincts are more or less plastic and susceptible of modification, this modification in some cases going so far as to result in the complete suppression of the instinct by unfavorable environmental conditions. Most of the instincts have a reasonably obvious biological utility, in that they contribute to the maintenance of the life of the individual or the species, and the same thing is true of the reflexes and, presumably, of the tropisms.

Among the various theories of the origin of this group of instinctive and reflex actions, two have been most frequently urged. The one derives its chief support from an examination of the supposed facts in the case of human beings. It assumes that the expression of life in its original forms was spontaneous and indefinitely variable. It further assumes that something comparable with volition is present in these primitive spontaneous expressions and that this volition is intrinsically intelligent, so that among the various spontaneous, or random, forms of movement which may be indulged there is presently a selection of those which are most useful and a suppression or elimination of those which are harmful. Whereupon it is further assumed that these beneficial spontaneous reactions become embedded as fixed habits which presently are transmitted by heredity to succeeding generations. They constitute on this theory a sort of frozen intelligence. Although this view has been held in times past by scientific men of eminence, it is certainly not looked upon with favor by any considerable number of contemporary scientists. It makes assumptions about inheritance which are at best very doubtful and assumptions about primitive intelligence which are highly improbable. Over against it is the view that, behavior being essentially a function of structure, reflexes, instincts, and tropisms simply represent accidental variations which have survived, just as the variations of form have survived, because they were, on the one hand, positively useful, or, on the other hand, sufficiently harmless to permit their continuation, if only they chanced to be combined with other reactions of a preservative kind. Both theories admit that, as things now stand, acts of reflex and instinctive character, whatever their evolutionary history, are as such intrinsically non-intelligent, non-adaptive to variation in environment. This is as true of man as of animals.

Again broadly speaking, it must be recognized that the range and complexity of animal instincts bears some relation to the organization of the central nervous system, but the relation is a highly complicated one. Certain arthropods, for example, like the ant, the bee, the spider, the wasp, have amazingly elaborate instincts, although the pattern of the nervous system is relatively simple. On the other hand, certain of the mammals whose nervous system simulates that of man himself are equipped with instincts of a seemingly less complicated and remarkable character. Unequivocal tropisms, as might be expected, are generally more striking and presumably more frequent in creatures of simpler type than in those higher up the scale. As is natural, instincts tend to follow patterns appropriate to the particular environment in which the animal thrives. Birds thus develop nesting instincts, which are quite different in form from any correlative instincts of fishes. The latter, on the other hand, develop spawning instincts, which vary in some essential particulars from the reproductive instincts of the birds and mammals. In discussing intelligence it is highly essential to keep constantly in mind these inherited forms of behavior and to distinguish them sharply from acts acquired by the creature of its own initiative.

With this brief background of general impressions regarding instinctive and reflex endowment of animals, we may turn attention to their more strictly intelligent behavior. At this point we are thrown back on two types of evidence whose relative value is estimated quite differently by different scientists. We have, on the one hand, the observations of the outdoor naturalist, who undertakes to describe the behavior of animals as seen under the typical conditions of nature. On the other hand, we have the experimental school, which has attempted to study and analyze the behavior of animals under laboratory conditions of control, or at least under conditions of a somewhat artificial character. Evidence of the first type tends to be anecdotal in character and, in the nature of the case, is rarely able to present any trustworthy account of the life history of the individual creature whose behavior is under discussion, or indeed of the immediate antecedents of the particular episode under consideration. It would be at once unjust and ungracious to deny substantial value to much of the information emanating from such sources. Indeed, with the case of the instincts nearly all of our knowledge derives from this source. But on the other hand, evidence of this character should be subjected to the most searching scrutiny, for to it attaches not only more than the usual dangers of inaccurate observation, but also the all but inevitable tendency to anthropomorphic interpretation. This is the happy hunting ground of the nature faker and of the manufacturers of Arabian Nights tales and Baron Münchhausen legends of animal life and behavior. None but a hopeless ingrate could recall Mowgli and his friends without a sentiment of deep and lasting gratitude; but, if taken as more than literary romance, the accounts of Kaa, of Shere Khan and the Banderlog, to mention no other instances, can only result in profound misapprehension.

On the other hand, the laboratory school suffers from the charge of subjecting animals to abnormal conditions, under which their reactions are distorted and in which it is impossible to expect normal expressions of their intrinsic intelligence. As regards the larger undomesticated animals, there is doubtless some force in this type of criticism, and indeed when it comes to certain forms of procedure, to be mentioned in an instant, it may be alleged with some show of proof, that the very conditions under which the observations are made tend to defeat their own purposes. For example, it is a not uncommon procedure in animal experimentation to create incentives to the solution of simple problems, either by creating strong hunger, or by the use of somewhat severe punishment. In either case, it is alleged that the animal is thrown into an abnormal emotional condition highly prejudicial to the exercise of such powers of intelligence as it may possess. Objections of this character are all appreciably less significant when urged against the milder and less unnatural forms of experimental procedure employed, let us say, in the case of simple marine animals, to whom can be given, under laboratory conditions, surroundings so closely simulating their native habitat as presumably to rob them of any real abnormality. Moreover, after every criticism has been recorded, it still remains true that, when affirmative evidence of intelligent behavior is secured under conditions of experimental control, whether inside or outside a laboratory, the validity of such evidence is likely to be forever exempt from the uncertainty which almost inevitably attaches to the incidental observations of animals in nature.

It is necessary to direct attention to these two main lines of attack upon animal intelligence, for the reason that observations which have been reported from these two sources have often varied fundamentally. The works of the outdoor naturalist, for example, are full of records of animal behavior alleged to afford the most unequivocal evidence of reasoning processes approximating those of man himself, whereas the experimentalists have with few exceptions failed to discern anything of this kind and in its place have reported literally thousands of instances of behavior apparently quite devoid of the inferential features of human thinking.

It will be readily understood that no observation of animal behavior is likely to be trustworthy, unless based upon a wide and exact knowledge of the animal's usual habits of life. Otherwise one is exposed to the error of interpreting as a rational process a piece of behavior which may be partly or wholly instinctive, or which may have been acquired by wholly unknown means at some earlier period of the animal's life.

When due allowance is made for such modifications as have been already suggested, the general upshot of the observations of the experimentalist may perhaps be summarized in this way. The very simple forms, like the low marine orders, exhibit a relatively limited group of reactions, some of them tropistic in character, others, however, seemingly somewhat variable, but few of them suggesting the exercise of essential intelligence. A little further up the scale, animal forms are encountered which are equipped with fairly definite instincts and which evince the ability to learn to accommodate themselves to changes of environment, but only by the slowest and most tedious processes, giving practically no indication of any trait which one would naturally designate intelligent. Thus the frog, for example, by earlier observers supposed to be entirely incapable of taking on any modified reactions by the process of learning, has now, through the most patient observations, been found to be capable, after many, many trials, of slightly improving his reactions. Granted, for example, two pathways, one of which always leads to food and the other not, he can, if the patience of the experimenter is sufficient, ultimately learn to choose the correct pathway. Still further up the scale, as will be illustrated in some of the lower mammalian forms, we get more positive evidence of the beginnings of real memory and of a more definite ability to modify reactions in a beneficial manner, although this capacity with some of the mammals, such as the guinea pig, is almost at the zero point. With others, however, and particularly with the primates, there is much greater adaptability, and in a few seemingly well-authenticated instances there is evidence for something at least suggesting the human forms of inference and thinking. This amounts to saying that there is in the animal kingdom, as we know it, the widest range of behavior extending from that which at one end of the line is almost, if not wholly, stereotyped and mechanical to forms which at the other extreme represent not only a rich life of plastic instinct, but also highly variable forms of behavior, some of which definitely suggest the possession of rudimentary intelligent powers. There is, then, conclusive evidence of a real evolutionary process, if one assume, as all scientists now do, that the more complex organisms, in which behavior is most elaborate and intelligent, have arisen from simpler and historically antecedent forms. That is to say, there is no question whatever regarding the wide variety of the present modes of behavior extending from the reflex and tropistic type up to the variable intelligent type, and, on the basis of the evolutionary conception of organic structures, there can be no question that these differences in behavior represent historic evolution of the more complex out of the simpler.

Intelligence and Consciousness

This is perhaps a convenient point at which to mention an issue often much magnified in discussions of mental evolution to wit: Are all animals conscious, or is consciousness a phenomenon which appears only at a certain stage of evolutionary development?

Disregarding earlier historic theories, there have been three distinct positions represented by contemporary scientific opinion. One of these holds that all animals are conscious, even an amœba. Indeed, the defenders of this extreme view have sometimes gone further in maintaining not only that all life, plant as well as animal, enjoys at least a rudimentary form of consciousness, but also that the whole physical universe is but one aspect of a reality, which seen in its entirety presents a corresponding conscious phase. Needless to say, we must eschew for present purposes any discussion of this larger issue.

There is, second, the view that consciousness appears in the evolution of the nervous system at that point at which there is demonstrable evidence that creatures can learn to improve their reactions on the basis of experience. From this point of view, the frog, among the more familiar of our animals, would represent perhaps the stage at which the first gleams of intelligence are discernible. Practically, this test is a very difficult one to apply, because it would be precarious to allege with confidence that, granted sufficient repetitions of a given situation, any animals would fail to show some modification in response. But purely physical and chemical reactions, for example the formation of crystals in minerals, exhibit a similar slow modification. And yet, in this case, one would hardly be disposed to allege the presence of consciousness. Furthermore, where animals low in the scale apparently display adaptive reactions, it is difficult to be certain that the chemical and physical stimuli affecting them are all under control, so that the seeming adaptation may be accepted as bona fide.

A third view holds that no animals are conscious, but that all their reactions are essentially of the mechanical and tropistic type. One must, of course, admit that we have no direct access to animal consciousness, if such exists, but the same thing is true of the consciousness of one's human neighbor.

It has seemed to me desirable to eliminate this whole issue from the present discussion, because we are primarily concerned with the demonstrable evidence of actions such as we can properly designate intelligent without regard to any particular psychic mould in which they may be cast. This is not because the question is devoid of interest—far from it—but because it does not lend itself to profitable discussion within the limits of this article, if we are also to make headway on the general problem of the evolution of intelligence.

Human Intelligence

How far the intelligence of modern man has developed beyond the stages of the prehistoric man, whose skeletons have in recent years come to light, it is practically impossible to state. Certain of these earliest remains indicate a cranial formation somewhat smaller than that of contemporary man and, although the evidence is precarious, there is perhaps some ground for thinking that the cerebral portion of the nervous system was less highly developed than now and that presumably the level of native intelligence was therefore lower. Nevertheless, this would be merely an hypothesis. If we turn to contemporary man, we find extreme variation in the culture and civilization of different races, and a widespread belief in equally marked differences in native intelligence. Thus the Occidental white man unhesitatingly puts himself at the head of the list, with the Asiatic ranking next, American Indians perhaps next, the African next, and at the bottom possibly the Black Fellows of Australia. This purely arbitrary list, of course, omits a number of important groups, but may serve to give some indication of a common type of arrangement. It is perhaps needless to say that the Asiatic in making out his list would accord a different position to his own group. Nor is any great racial stock disposed to accept an inferior status.

The question which is immediately raised by the most superficial inspection of these racial differences of culture and civilization has to do with the problem whether the European white man, for example, has by virtue of superior native endowment passed by evolutionary processes through stages of culture and civilization comparable with some or all of those now reflected in the several racial groups mentioned, or whether he has had an altogether different history. Have the civilized races, in general, evolved through superior intrinsic talent out of the conditions represented by savage races? The problem is greatly complicated by the difficulty of separating out those factors which are indicative of sheer intellectual capacity and those which have to do with the accidental advantages of climatic or geographic habitat and the equally accidental developments of particular technical or social practices. It is easy to assume that more elaborate forms of civilization *necessarily* imply higher intellectual powers and this is perhaps not wholly true. So far as we can judge by the evidence in historic times, there is no reason whatever to suppose that the native intellectual abilities of the average American citizen are in any way superior to those of the Egyptians four thousand years before Christ, or the Homeric Greeks, or to others of the peoples of that general period in the Mediterranean basin, records of whose civilization have come more or less completely to our knowledge. It would certainly be a bold protagonist who should assert that modern European civilization has produced, in sheer intellectual power, men superior to Democritus, or Plato, or Aristotle, or Alexander, or Julius Cæsar, to say nothing of great Orientals like Confucius. In other words, since the period of historic records there is no convincing evidence of marked development in human intelligence, despite the enormous advances made in the paraphernalia of civilization; but, on the other hand, there is fairly definite evidence that extant human races differ appreciably in their native intelligence and those which are living most nearly in the state of nature which we believe to have characterized the early history of our own racial stock are, generally speaking, marked by apparently lower general average intelligence and by relatively fewer intellects of high grade. It seems therefore a reasonable inference that the forefathers of our own particular racial stock, could we but penetrate far enough into past history, would be found, like the more primitive races to-day, in possession of somewhat lower degrees of intellectual capacity. How many thousands of years we might be obliged to go back to find demonstrable changes it is impossible to say. We know that the major anatomical characteristics of man have not materially shifted for the last twenty or thirty thousand years—possibly for much longer.

There is a very common popular belief that, although civilized man may be the superior of his uncivilized contemporary in certain forms of purely intellectual activities, he is his inferior in keenness of sense perception and in his response to many of the aspects of nature. Such evidence as we have tends on the whole rather to discredit both of the inferences involved in this assertion if they be made too sweeping. It is surely open to question whether all races of nature people now living are radically inferior to the more civilized groups in natural powers of intelligence. Certainly there are some striking individual instances of high intellectual achievement attained by representatives of some of these more primitive racial groups; and, on the other hand, there is good evidence for the statement that at least occasional representatives of civilized races are quite as keen in their vision and hearing—taking these two examples—as any of the primitive peoples with whom they may be compared. The North American Indian and the white frontiersman may illustrate the point. There are not a few instances of Indians who have exhibited intellectual capacities of a very high order, and the keenness of vision and hearing of some of the scouts of frontier history rival anything reported of their savage contemporaries. Training and discipline are perhaps in both cases the clew to achievement quite as much as deep-seated and indisputable difference of natural capacity—a statement which in turn must not be understood as implying that there are no significant differences between the lowest tribes of savages and the highest exemplars of civilization.

If, as a clever writer on these subjects has suggested, we may consider existing tribes of savages as in some sense our contemporary ancestors, it is convincingly clear that, whatever is to be said of sheer native intellectual capacity, civilized man has developed a technique so superior to that of primitive peoples that his intelligence enjoys enormous advantages at almost every stage. It is peculiarly difficult for us to dissociate mere intellectual power from the cultural surroundings under which it is exercised. It may be, for example, that the inventor of the bow and arrow accomplished quite as great a feat in the intellectual world of his day as the inventor of printing in his, or the inventor of the steam engine, or the inventor of the electric light. Similarly, the inventor of the fishhook and the line, as a method of extracting food from the sea, may have enjoyed powers of native intelligence entirely comparable with those of our great modern inventors. All of which is but another way of saying that the evidences of the evolution of civilization and culture are far more striking and far more demonstrable than those which suggest, in historic times at least, any real progress in the intrinsic fabric of human thought. Moreover, in all comparisons of racial groups one must remember the astonishing variation of natural capacity in any large number of people. The psychological tests employed in the American army during the war exhibited the amazing range of capacity in a cross section of our population. Certain of the recruits in the army exhibited an intelligence capacity which marked them as morons and accordingly comparable with the most backward races. One is always tempted when comparing one's own racial group with another to take as the standard one of its very intelligent members. This is entirely unfair and sure to result in fallacious conclusions unless one is in a position to select from the group under comparison an equally exceptional representative.

But, after all allowances are made, it would appear that, if we compare the normal civilized man of any of the more advanced races with those savages lowest in the human scale, the former is probably superior in the power of sustained attention and thought, in the range of things which interest him, and in his powers of analysis, abstraction, and inference. It used to be alleged that savages controlled their emotions less perfectly than civilized man. Inasmuch as emotional life is closely knit up with instinct and with the more primitive and ancient part of our nature, it would not be strange were this belief true. But when consideration is given to the different conditions eliciting emotion, it may be doubted whether this conception is in any unqualified way correct.

That portion of the history of man marked by any of the evidences of civilization is so extremely brief, compared with the vaster period of animal barbarism through which he must have passed, that we may well find it difficult to secure wholly conclusive evidence of evolutionary change in his mental powers. But such evidence as there is all points to a great *practical* improvement in the use of his native abilities.

When we contrast the conditions of savage man with those of any of the animals, even the highest primates, the differences in apparent intelligence are very marked. It would hardly be a safe statement that animals make no use of gestures, whether vocal or otherwise, to serve the purposes of a rude language. But such use as has been reliably demonstrated is so crude, so largely a mere expression of emotional excitement, that compared with developed human speech (which presumably developed out of emotional expressions) it is an extremely imperfect tool. Primitive man as we know him, although often carrying on his affairs with a relatively limited vocabulary, nevertheless is able, through his language devices—to say nothing of others—to mark off and deal with abstract and general relations, and in so far he enjoys a technical superiority to the animals which, in effect, is a difference in kind as well as a difference in degree. Moreover, broadly speaking, animals apparently make no use of tools. The occasional instance of the elephant brushing off flies with a branch held in his trunk, or the reported instances of monkeys using stones to crack nuts, are but sporadic examples of possibly accidental achievements which in no case lead on to any general ability to make use of utensils in a discriminating way. One must not, in this connection, confuse with intelligent actions the remarkable instinctive manipulations which many animals are capable of, nor the tricks which they may have been taught by long and painful effort. The elaborate nests which many birds build are amazing instances of utilizing the most varied materials in highly complicated forms. Similarly, the beavers accomplish the most astonishing results with the materials which they employ and there are abundant reports of their adaptability to changing conditions which, if well-established, are certainly suggestive of highly intelligent reactions. Here again, however, the experimental zoölogist who has studied most carefully the instinctive activities of animals will be most hesitant to ascribe individual intelligence comparable to that of man in interpretation of these animal reactions. Certain it is that, generally speaking, the primates are much more skillful than other animals in adapting themselves to shifting conditions and that, even among them, with the exception of certain of the great apes, the evidence of anything comparable with a human process of inference, or a process of abstracting, or of generalizing, is slight. Recent observations on the orang and the chimpanzee, however, disclose in certain instances reactions which closely resemble human identification of cause and effect relations in practical situations; *e.g.*, removing an obstacle to close a door. In any case, the issue which is raised here again must be clearly understood, to wit, that beyond the adjustments which are innate, inherited, and not learned by the individual are those which represent his individual acquirement independent of such inherited tendencies. The latter is the field of individual intelligence.

As was indicated earlier in this paper, there is a wide general correspondence between the degree of intelligence manifested by animal forms and the structure of the nervous system. In particular, intelligence in its narrower and more specific sense, as distinguished from instinct, appears to be rather a function of the cerebrum and particularly of the cortex. If animals are arranged in the order of the development of this organ in the nervous system, the relative size and complexity of it will be found standing roughly in parallel with the variety and adjustability of the reaction patterns. That is to say, an animal that has a well-developed cerebral cortex will have a richer type of behavior, being less completely dependent upon instincts and reflexes and being capable of carrying out a larger range of activities than can an animal with less fully developed cerebral structures.

Man has, as the great differentiation of his own brain from that of most other animals, a very much more delicate internal structure in the cortex and relatively very much larger parts of the cortex devoted to the interconnecting and interrelating of the various parts of that organ with itself. The frontal areas and the so-called association areas are relatively very large. Some of these differences are demonstrable only under the microscope; others, however, are obvious even in the gross anatomy. But despite these differences which are real, no one could ever have inferred from them such marked differences in the expressions of intelligence as do in point of fact distinguish man from even the most highly developed animal. The general pattern of the human nervous system is, broadly speaking, exactly that of wide ranges of the mammals and more particularly of the primates. Nevertheless, the behavior of man is certainly very different (even though the difference be thought of as merely quantitative and not as qualitative), especially on the levels of memory, imagination, thought, and reflection. On the whole, man's development and control over language is unquestionably the greatest single achievement which his intelligence has compassed, and whether one thinks of it as cause or effect, its presence, more than any other one factor, is responsible for his enormous superiority to his animal neighbors. It has enabled him to achieve social coöperation and the fixation of institutions, to preserve tradition and modify its coercive influence by rational discussion, and incidentally it has afforded him the most powerful single tool for creative individual thinking.

The striking character of the difference between typical human processes of inference and those by which most animals acquire wholly new reactions may be illustrated by a single example. Here is a dog shut up in a cage with his food just outside the door. To open the door and satisfy his hunger involves pulling a cord which lifts a latch. No matter how obvious the arrangement to human vision, the dog may thrash about for a long time in the neighborhood of the cord, biting and clawing the various parts of the cage, until by accident he may seize the cord in his teeth and forthwith escape. A human being having once found a single act which would thus open the door would ordinarily require no second experience instantly to repeat the success. But the animal may need many such trials before establishing the correct response, showing that there is very slow discernment, or possibly none, of the real relation of the cord to the opening of the door.

Now human beings do many things quite similar to the random activities of the animal in the cage. Many a child attempting to solve a mathematical problem does exactly the same thing and comes upon the correct result, if at all, quite accidentally and as the outcome of a kind of mental fumbling. Indeed, all elaborate thought processes inevitably have in them much of this more or less haphazard experimental venturing. But the point is that once the human being clearly sees the relation involved, he can immediately repeat successfully the process and generally carry over the principle to other similar but not identical problems. It is questionable if animals ever do just this thing. Even their powers of imitation are probably far less developed than is commonly supposed.

So, despite the structural similarity of the brain of man and the brain of the higher mammals, the differences in intelligent behavior are very marked. The most intelligent animal is presumably in the mental condition of the young baby or the very low grade moron, and this despite the possession of instincts which often enable the most astonishing adjustments to environment.

Future Development of Human Intelligence

In one of the later chapters (Chapter XII) a question of importance is discussed, to which a further word may perhaps be added in this connection. Is the evolutionary process at an end so far as concerns the human brain and human intelligence? In the nature of the case no dogmatic reply can be offered with confidence and one must fall back upon the probabilities of the case. I cannot altogether sympathize with the somewhat definite negative opinion occasionally advanced, for such negation has its chief justification in the vast extent of time throughout which little or no demonstrable advance has occurred in the organization of the human brain and therefore presumably in human intelligence. One cannot challenge the fact that for many thousands of years there has been little or no such change; but, on the other hand, the period of time for which we have such evidence, twenty or thirty thousand years, is so trifling compared to the total life of the race and the total duration of life itself on this planet, that a prediction based on such a relatively insignificant segment of man's history seems highly precarious. Assuming some extra-mundane observer of the primeval slime out of hich organic life has come, it would certainly have seemed o such an one grotesque to predict such changes as have actully come to pass, and particularly as regards intelligence. imilarly it is entirely impossible to surmise at what point rogress beyond present human capacities may occur, but to onclude with any certainty that such further progress will not ccur, much more that it cannot occur, seems hardly warranted.

Whether this view regarding the further evolution of inrinsic human capacities is right or wrong, there would appear o be no practical limit to the changes which man can hope to ring about in the conditions of his life by the further appliation of the same technique which has produced the highest orms of modern civilization, has produced our fine arts, and, articularly, has produced our modern science. Conceivably e shall never have greater epic poetry than that of Homer, reater sculpture than that of Phidias, greater architecture han that of the Parthenon, greater drama than that of Shakepeare, greater painting than that of Raphael and Titian, reater symphonic music than that of Beethoven. There is, owever, nothing to prevent advance upon such achievements nd in the range of the natural sciences at least, thanks largely o the perfection of experimental technique and the utilization f mathematics, there seems to be literally no limit in sight to he further mastery which man may achieve over the forces of ature and consequently no limit to the alterations which he nay be able to introduce to the enrichment of civilization. ven in the field of religion, where obvious evolution has ccurred since primitive times, the modern mind has introluced modifications of the teachings of the founders of the reat world religions designed to adapt them more nearly to he conditions of contemporary life. The doctrines of Chrisianity itself, while based as truly as ever upon the life and eachings of Jesus, are undergoing constant development and ransformation designed to accommodate them to the needs of the life and thought of our time. Strangely enough, the scientific mastery of the facts of man's own nature and the laws which control society linger far behind the corresponding insight into the nature of the processes of the physical world. But surely it is only a matter of time when these social sciences, so-called, will also have perfected a technique enabling man to secure mastery over himself and his social relations comparable with that which has begun in the control of physical nature.

In modern times, to mention but a single point, our knowledge has been rapidly growing in regard to the extent to which the mental life of the individual human being is subject to influences which rarely or never show themselves above the level of his conscious life, and, even upon these infrequent occasions, come so screened and shrouded that their real origin is seldom understood or appreciated. It has thus been made particularly clear in the last century that man is in his instinctive life close cousin to the brutes. But he has also in his nature the deep grounded tendencies of hundreds of thousands of generations of savage human ancestors. Furthermore, he carries into his adult life many prejudices, fears, likes, and dislikes, which trace back to his own infantile and childhood experiences. Any of these tendencies may well up at a moment's notice to affect the attitude which he takes toward any issue that may present itself in his life. He may make a decision which, with a not unnatural self-flattery, he calls a carefully reasoned choice. But to a sufficiently informed observer it would frequently be revealed that this reasoned choice represented an attempt to justify on rational grounds an impulsive preference arising from some of these hidden springs in human history, rather than a wholly disinterested and unbiased analysis of a given situation. Moreover, man at birth finds himself instantly surrounded with all the traditions and practices of his own time, race, and social group

hich from the very beginning hem in his spontaneous activi-
es, furnish the stage upon which his instinctive and impulsive
fe must be played, and, in general, set boundaries which, how-
ver independent, he can hardly cross. In point of fact, the
verage individual is intensely conservative, indisposed to the
bor and the hazard of independent thinking, a creature of
abit, most content when most easily able to run along in the
xed grooves of daily life without friction or annoyance.

Nevertheless, while the average individual may be intrin-
cally indisposed to encourage change, except in those circum-
ances which occasion him personally acute discomfort, the
ore active and progressive minds find through the accumu-
ted knowledge of the race, now for a few centuries available
permanent written form, and through the amazingly rapid
evelopment in the technique of the sciences, the tools at hand
or a literally unlimited evolution in the actual conditions of
uman life. From this practical point of view, therefore, the
volution of intelligence may be considered as close to its be-
innings rather than in any sense drawing near to its close.

CHAPTER IX

CULTURAL EVOLUTION

GEORGE GRANT MAC CURDY

RESEARCH ASSOCIATE IN PREHISTORIC ARCHEOLOGY, YALE UNIVERSITY;
DIRECTOR AMERICAN SCHOOL OF PREHISTORIC RESEARCH

Cultural evolution has to do with the products of man's brai and hand. It was preceded in time by a period of physical evolution during which the forelimb ceased to function primaril as a means of bodily support and locomotion. During thi same period, the brain shifted from being suspended at the en of a horizontal vertebral column to a position at the summit o a vertical vertebral column. The acquiring of stereoscopic v sion was one of the results of this shift. Nor was it enoug that the forelimb should no longer need to function as a mean of support and locomotion. It was the human arm and han with four fingers and opposable thumb, capable of pronatio and supination that has made all things possible to the huma brain. A forelimb of the horse- or ox-type, for example, wou have closed forever the bars to human progress. Lucky it w also that the human forelimb did not develop into a win which never could have served as a substitute for arm and han in responding to the brain's behests. It would be difficult to sa how long it took for this special and beneficent partnership b tween brain and hand to become a reality. The period was very long one; as has been also the period since the partnershi first became effective and cultural evolution began. Chang have taken place in both brain and hand since then but the have been insignificant in comparison with the progress of cu tural evolution.

We of this generation are so accustomed to lightning hanges in our cultural environment that it is difficult for us to onceive of a time when a single lifetime did not suffice to wit- ess any appreciable change in this respect. Some of us who re living to-day have witnessed greater changes in methods of ransportation of objects and in transmission of messages than ccurred during all the preceding generations combined.

There was a time when everything that was made was hand- ade. This was true of that first and longest period of cul- ural evolution known as the Old Stone Age. All the work of he world was done by man—either free or slave. There fol- owed a shorter period when man learned to shift some of his urdens to animals tamed for that and other purposes. This as the New Stone Age. The next outstanding event in the istory of human progress was ushered in with the use of etals, without which a machine age properly speaking would ot have been attainable.

With the advent of the machine age, the hand has once more ained a new freedom. The great mass of the work of the orld goes on without its direct participation. Machinery has lso relieved the brain of much of its mental load. The result that an ever increasing number of brains and hands are left ree to solve problems other than those of mere production, or hat minister to mere existence. The cultural evolution of the istoric era therefore looms large, but it should not be per- itted to hide from view that of the prehistoric era, without a roper conception of which we cannot hope to have a true per- pective of cultural evolution as a whole.

The birth of prehistory as a science may be said to have aken place when C. J. Thomsen of Denmark laid the founda- on for a system of prehistoric chronology. With the coöp- ration of a number of Danish and Swedish scientists including orchhammer the geologist, Nilsson the zoölogist, Worsaae, nd others, Thomsen succeeded in establishing on a scientific basis a relative chronology for prehistoric time. Thomsen began to make use of this system in 1830, but he did not publish it until 1836.[1] His researches gave confirmation beyond the shadow of a doubt to beliefs which had been expressed by men of thought and vision even before the beginning of our era Thomsen's classification provided for a sequence of cultures representing three ages: Stone, Bronze, and Iron. His system applied to the collections in the National Museum at Copenhagen, of which he was director, was soon accepted in Scandinavia and throughout the world.

Prehistory as a science therefore will very soon be one hundred years old. Although progress has been comparatively rapid during the last hundred years, the science is still in an early stage of development. The reasons why the scientific study of man's remote past has had such a tardy beginning are not far to seek. Man must perforce be his own examiner and classifier and sit in judgment on the results of self-investigation, a doubly difficult task made all the more difficult through pitfalls of myth, prejudice, and superstition.

Prehistory is a subject of three dimensions—two geographic and one geologic. From the latter we gain some idea as to the length of time that has elapsed since man first appeared on the earth; from geography we hope to learn something of the distribution of prehistoric cultures and races over the face of the earth; lastly the geographic and geologic data combined should make it possible to determine approximately where man's first appearance occurred. It is obvious therefore that before the science of prehistory could be developed, it had to await the prior development of our knowledge of geography and geology. With the extension of geographic knowledge through voyages of discovery, there were revealed hitherto unknown races in a primitive stage of culture. A study of their cultures and physical types afforded very important means of compari-

---

[1] *Ledetraad til nordisk Oldkyndighed.*

on with prehistoric races and cultures; so that both ethnology
nd prehistory have been the gainers from geographic re-
earch.

In history and prehistory, a single genus of the animal king-
lom—man—occupies the center of the stage, whereas natural
istory deals with the story of animals and plants. In many
arts of both the Old World and the New the passage from the
rehistoric to the historic era took place only a short time ago;
owhere, not even in Egypt and Mesopotamia, does it exceed
nore than about five thousand years. This is but a mere drop
n the bucket as compared with the hundreds of thousands of
ears covered by the prehistoric era.

In attempting to trace the limits of prehistory, certain basic
acts must be kept in mind. In the first place there is probably
o considerable area anywhere on the face of the earth, with
he possible exception of the circumpolar regions, which does
ot have its background of prehistory. This means that pre-
istoric man spread over the entire habitable globe and was
ither already there when historic man arrived, or had been
here and disappeared before the appearance of historic man.
econdly, the greater part of the land area in each hemisphere
ies north of the equator, and the land area in the eastern hemi-
phere or Old World is much greater than that of the western
emisphere or New World. Thirdly, man appeared in the
ld World before he did in the New World, and the historic
ra is likewise longer in the Old World than in the New. In
he fourth place, the earliest scenes in the human drama are
nseparably linked with the Ice Age.

THE ICE AGE

By the Ice Age we mean the series of four cold epochs which
egan some hundreds of thousands of years ago and lasted un-
il some twenty-five thousand years ago. During these cold

epochs, the ice of the polar region spread until it invaded what are now temperate regions. It also accumulated in elevated regions like Switzerland and spread in all directions far beyond its present limits. Each cold epoch was succeeded by a warm epoch in which the climate was not unlike, or even warmer than, that which exists to-day. The Ice Age was therefore composed of a series of cold or glacial epochs alternating with warm or interglacial epochs. The fauna and flora, animal and plant life, varied with the climate. Man lived during both glacial and interglacial epochs, for we find his bones and the products of his civilization at a given locality in a series of deposits containing a fauna suited to a glacial climate alternating with a fauna suited to an interglacial climate. (See pages 150–151.)

It was a fortunate circumstance that gave our ancestors their first foothold in the Old World. The land mass was not only much greater there than in the New World, but the area covered by the ice of each glacial epoch was also proportionately much less; that is to say, the great continental ice sheets, spreading from the North Pole, reached more southern latitudes in North America than in Europe and Asia, thus leaving to man a correspondingly more ample stage for the great drama of physical and cultural evolution than he would have had in the western hemisphere. Whereas the maximum extension of the ice front reached as far south as New York and Cincinnati, which are on the same parallel of latitude as Naples, the corresponding ice sheet in Europe stopped a little short of London, which is on about the same parallel of latitude as southern Labrador.

There is every reason to assume that the cradle of the human race was not only somewhere in the Old World, but also north of the equator. Was it in that part now know as Europe? It is too early to answer this question definitively. We are however in a better position to discuss the prehistory of Europe than that of any other section of the Old World because more work has been done there than anywhere else.

During the relatively short historic era, one deals with a chronology which may be called certain or absolute. When it comes to the prehistoric era, one has to be content with approximations—with relative chronology—as is the case when dealing with the Ice Age or with geologic time, of which it is a part. This fact, however, does not reflect on the soundness of prehistoric chronology, or on its scientific value. Where we have to deal with such big units of time, a difference of opinion of even thousands of years is no very serious matter. In consulting various authorities therefore, one should not be surprised to find differences of opinion concerning the length of time which has elapsed since the beginning or the end of the Ice Age. For example, we are told by some that it began about a million years ago and lasted until some twenty thousand years ago. Others would reduce its duration by about one-half, usually by lopping off the first few hundred thousand years.

One geologist would reduce the sum total by lopping off at both the beginning and the end, placing the beginning about 600,000 years ago and the end some 70,000 years ago. Another believes the last glacial phase continued down to at least some 25,000 years ago. However, it is not within the province of the prehistorian to tinker with a problem primarily geological. The geologist also tells us that the beginning of the Ice Age coincides approximately with that of the Quaternary or last of the four great divisions of geologic time. Here again we prehistorians accept his dictum.

But if the prehistorian would dig down to the very roots of the human family tree, he must go farther back in time and deeper into geologic strata than the beginning of the Quaternary or of the Ice Age. The stem from which the human stock sprang may be traced down into the period immediately preceding the Quaternary, known as the Tertiary. (See page 151.)

After three months of field work in Europe, during the summer of 1903, I returned to America fully convinced that our forerunners had lived in the Old World at least as far back as the Pliocene, which is the last or youngest epoch of the Tertiary Period. I made a report to this effect before the American Association for the Advancement of Science in 1903. At that time there were few who had the hardihood to share this view with me. In the twenty-five years that have elapsed since then, I have passed from the ranks of the radicals to those of the conservatives without having had to change my views materially.

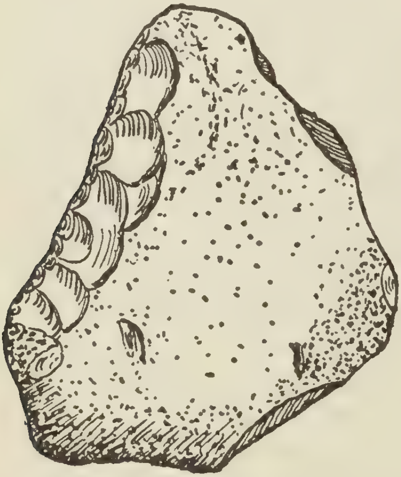


Fig. 58.—Chipped flint from the Chalk Plateau in Kent, England, and dating from the Eolithic Period. During this period both natural and artificial flakes were used as knives and scrapers. After Reid Moir. 1/1.

Man has had, then, not only a big stage on which to unfold the earliest scenes of the drama of civilization, but likewise a generous allowance in so far as the time element is concerned. As might be expected, the gradually unfolding records prove that the evolutionary processes, both physical and cultural, have been very slow indeed, especially during the long lapse of time preceding the first appearance of a human type enough like modern man to belong to the same species, *Homo sapiens.* The oldest representatives of this type belong to what is called the race of Cro-Magnon. This race inhabited Europe coincident with the last cold epoch of the Ice Age, say some fifty thousand years ago.

In terms of prehistoric chronology, this is the beginning of a

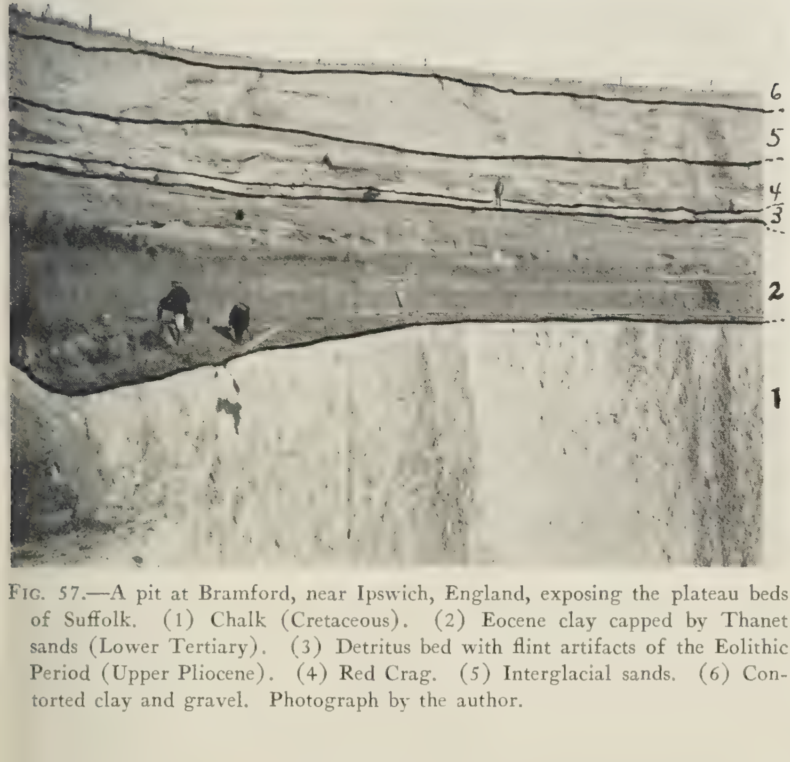


FIG. 57.—A pit at Bramford, near Ipswich, England, exposing the plateau beds of Suffolk. (1) Chalk (Cretaceous). (2) Eocene clay capped by Thanet sands (Lower Tertiary). (3) Detritus bed with flint artifacts of the Eolithic Period (Upper Pliocene). (4) Red Crag. (5) Interglacial sands. (6) Contorted clay and gravel. Photograph by the author.

late phase of the Old Stone Age, known as the Aurignacian Epoch. This epoch marks an era of unusal significance in the domain of human evolution. Until then man's thoughts, as reflected in his kit of tools and the coördination of the brain and hand, which gave rise to his culture, were quite simple. After that time there was a speeding up of cultural evolution. This change was due in a great measure to an increase of facilities for translating individual experience into racial experience.

MEASURING PREHISTORIC TIME

Prehistoric chronology is founded on a knowledge of the sequence of deposits containing the prehistoric records; hence the terminology is not unlike that used by the geologist. It is based primarily on the cultural remains—the products of man's brain and hand—rather than the skeletal remains of man. The reasons for this are two: (1) cultural remains are more abundant; and (2) cultural changes have taken place more rapidly, are more easily observable, and form a more delicate method of measuring. The first tools were obviously ready-to-hand objects such as a stick of wood, a stone, or the bone or horn of an animal. It would be difficult to say which one of these three had precedence over the others in point of time. For obvious reasons it would not seem wise to speak of an age of wood even if there had been one; chief of these is the perishable nature of the material. Even bone is less durable than stone. So that the earlier big divisions of the prehistoric era are based alone on cultural remains made of stone, and the later divisions are based on cultural remains made of metal. Stone and metal therefore may be looked upon as furnishing the hard parts in the anatomy of the human culture as a whole, and as corresponding to the bony framework of man and fossil animals which remains after the soft parts have fallen to decay.

The prehistorian has followed the example of the geologist by choosing certain well-defined prehistoric sites as type stations for the epochs into which the prehistoric periods are divided. Thus one epoch of the Paleolithic Period is called Acheulian for a sand and gravel pit at Saint-Acheul near Amiens, France. In like manner the village of Hallstatt in the Austrian Salzkammergut gave its name to the first epoch of the Iron Age. This, however, can hardly be called a hard and fast rule, for Roman numerals, instead of place names, are employed to designate the various epochs of the Bronze Age—the exception required to prove the rule. (See page 285.)

Primitive peoples have a vague appreciation of their own prehistoric past, the vagueness being due to the fact that their knowledge of it is based on myth rather than on observation of the only records which are capable of throwing any light on the prehistoric. Even after a people enters upon a true historic era, its ideas concerning the era lying back of the historic often continue to be vague for a considerable lapse of time. This is especially true of the Old World peoples who were the first to appear on the historic horizon. It has taken some of them at least five thousand years to rid themselves of the yoke of myth and superstition; and the science of prehistory has done more in the last hundred years to rid the world of these than perhaps any other agency. Both credit and honor therefore should go to those whose exceptional powers of discernment have combined to make prehistory what it is to-day.

The course of progress has always been and will continue to be thought out by the gifted few. The rate of progress has always depended and will continue to depend on the ability of the many to profit by the achievements of the few. An individual may achieve something wonderful, but if this fails to register, to take effect in the minds of the many, it falls little short of an abortive attempt so far as results are concerned. Thus, many an idea fraught with great possibilities has died with its author. Then there is the idea that passed into a state f coma upon the death of its originator and was later luckily esuscitated by one of the gifted few. In both cases the time vas not wholly ripe for launching the idea. There is a third lass of new ideas whose originators are fortunate enough to ive to see the full fruition of their thoughts. It follows therefore that the time when a great event happens, a great idea is aunched, is not so important so far as progress is concerned s the time when the event or the idea takes effect and begins to ear fruit.

We cannot name any concrete examples of the first class, for n it belong the "mute inglorious Miltons" of whom the number is legion. To the second class belong the Freres, the Mendels, the Sautuolas, who did not live to see the sprouting in ther minds of the seeds they had sown. As examples of the hird and more fortunate class we may cite such names as oucher de Perthes, Lartet, Darwin, who lived to see the ruition of their labors.

It mattered little to men living in the darkness of the Middle ges that some 850 B.C., Hesiod spoke of a time when bronze ad not yet been superseded by iron; that Lucretius (98–55 .C.) had said: "The first weapons were the hands, nails, eeth, stones, branches broken from the trees; to these were dded fire, but a long time elapsed before the discovery of ronze and iron. Bronze was the precursor of iron." The an who discovered in 1690 the first paleolithic hand ax of lint at a considerable depth under what is now the heart of London and recognized it as a prehistoric artifact, fared little etter at the hands of his contemporaries and immediate descendants. The incident had been forgotten when in 1797 John Frere made a similar discovery but on a grander scale at Hoxne in Suffolk. And still the time was not ripe. The significance of John Frere's discovery failed to take effect. It remained for Boucher de Perthes with a persistence and a vision far beyond the ordinary to convince the scientific world of

CHART OF PREHISTORIC PERIODS

- Iron Age
  - La Tène Epoch (500 B.C.-1 A.D.)
  - Hallstatt Epoch (1,000-500 B.C.)
- Bronze Age (3,000-1,000 B.C.)
  - IV
  - III
  - II
  - I
- Stone Age (1,000,000-3,000 B.C.)
  - Neolithic Period (12,000-3,000 B.C.)
  - Mesolithic Period (20,000-12,000 B.C.)
  - Paleolithic Period (500,000-20,000 B. C.)
    - Upper
      - Magdalenian Epoch
      - Solutrean Epoch
      - Aurignacian Epoch
    - Middle
      - Mousterian Epoch
    - Lower
      - Acheulian Epoch
      - Chellean Epoch
      - Pre-Chellean Epoch
  - Eolithic Period (1,000,000-500,000 B.C.)

are very short in comparison with either the Eolithic Period or the Paleolithic Period. The Paleolithic Period alone covers a span of about a half million years, the Upper Paleolithic being the shortest of the three subdivisions. The chart is based on our knowledge of European prehistory. The latest discoveries tend to confirm the view that it may eventually be applied without slight variations to the rest of the Old World. We must however keep in mind that, for Europe alone, the beginning and the end of a given phase of the Stone Age were not everywhere contemporaneous.[3] The same is true of the Bronze and Iron Ages; for the use of metals was known in the Mediterrathe reality of a prehistoric past, long antedating anything that had, until then, been conceived of.

---

[3] The figures in the chart are valid approximations for the Mediterranean region.

The final success of Boucher de Perthes did much toward making it comparatively easy for Edouard Lartet only a few years later to prove by discoveries in cave deposits that the dawn of the fine arts occurred during the last glacial epoch. It was the head of a bear engraved on a piece of deer horn from the cave of Massat (Ariège) which first attracted Lartet's attention. Then followed in quick succession similar discoveries by him at Bruniquel and in the Vézère valley. The finds made at Bruniquel were in a cave owned by Vicomte de Lastic, who decided to take over the digging himself. He found a number of examples of cave art which were offered to the Louvre. Unfortunately for France, Longpérier, curator of antiquities, failed to appreciate their significance, so they went to the British Museum instead. Switzerland lost to Germany the browsing reindeer from Kesslerloch for similar reasons. These things would not have happened if Lartet's views had only gained credence a little sooner.

CHART OF PREHISTORIC PERIODS[2]

A chronological chart of prehistory is so constructed as to read from the bottom up in harmony with the order of the strata of the earth, the basis on which it is founded. This means that the most recent epoch will appear at the top of the chart, just as the most recently formed stratum of the earth's crust lies above strata formed in previous ages. Such a chart may be expressed in simple outlines as shown on the opposite page.

Our attention is immediately fixed on the enormous length of the Stone Age. We notice that the last two periods of this age

---

[2] MacCurdy, George Grant, "Human Origins," New York, 1924.

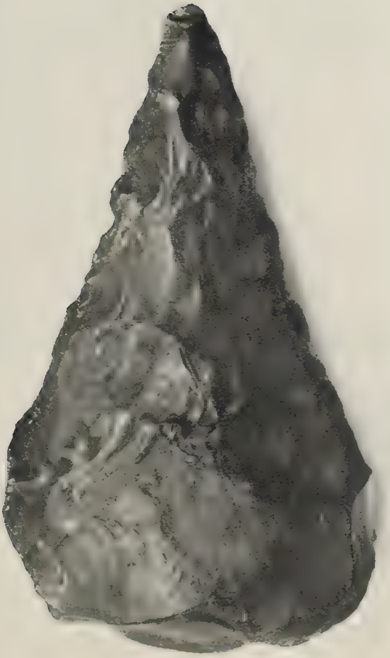


Fig. 59.—Hand ax of flint found in Pleistocene gravels at Gray's Inn Lane, London, about 1690. It is chipped on both faces and is the first chipped flint implement ever recognized as the work of ancient man. Chellean Epoch (Paleolithic Period). About 2/3.

CHART OF PREHISTORIC PERIODS

- Iron Age
  - La Tène Epoch (500 B.C.-1 A.D.)
  - Hallstatt Epoch (1,000-500 B.C.)
- Bronze Age (3,000-1,000 B.C.)
  - IV
  - III
  - II
  - I
- Stone Age (1,000,000-3,000 B.C.)
  - Neolithic Period (12,000-3,000 B.C.)
  - Mesolithic Period (20,000-12,000 B.C.)
  - Paleolithic Period (500,000-20,000 B. C.)
    - Upper
      - Magdalenian Epoch
      - Solutrean Epoch
      - Aurignacian Epoch
    - Middle
      - Mousterian Epoch
    - Lower
      - Acheulian Epoch
      - Chellean Epoch
      - Pre-Chellean Epoch
  - Eolithic Period (1,000,000-500,000 B.C.)

re very short in comparison with either the Eolithic Period or he Paleolithic Period. The Paleolithic Period alone covers a pan of about a half million years, the Upper Paleolithic being he shortest of the three subdivisions. The chart is based on ur knowledge of European prehistory. The latest discoveries end to confirm the view that it may eventually be applied with ut slight variations to the rest of the Old World. We must owever keep in mind that, for Europe alone, the beginning nd the end of a given phase of the Stone Age were not everyhere contemporaneous.[3] The same is true of the Bronze and ron Ages; for the use of metals was known in the Mediterranean region much earlier than in Scandinavia or in the British Isles.

---

[3] The figures in the chart are valid approximations for the Mediterranean egion.

In this brief sketch it is impossible to include a discussion of the prehistory of the New World. Moreover there are already sufficient data culled from Old World sources with which to make a more or less connected story from the Tertiary Period of the geologist down to the beginning of the historic era. In this vast field one can only touch upon the major influences underlying and controlling the current of evolution both cultural and physical. Of these the acquisition of speech and the taming of fire are two of the earliest big factors. In the following few pages we shall stop for a moment to view the men of various prehistoric eras, examining them in the order of their civilizations upon the earth.

Men of the Stone Age

In comparing the remains of man's handiwork, there are certain broad distinctions to be drawn. Eolithic industry of the Old Stone Age consisted largely of improvisations—of tools such as the hammerstone and the flint with utilizable edge or point. Both are products generously furnished by nature. Where utilizable chips were lacking, man soon learned to produce them artificially, thus supplementing his kit of primary or natural tools by secondary or artificial ones. The flint chip, produced by man and retouched intentionally to make it serve its purpose better, is an example of one of the earliest of artificial tools. Secondary tools remained few and simple for a long lapse of time, in fact throughout the Lower Paleolithic Period. The Neandertal[4] or Mousterian races of the Middle Paleo-

---

[4] So much is being said about Neandertal man that it is time those who use the term should come to an agreement as to how it should be spelled as well as pronounced. The original spelling was with an "h" although the "h" was never pronounced by the Germans. Now that the German *Reallexikon der Vorgeschichte* has set its seal of approval on a practice already in vogue among both

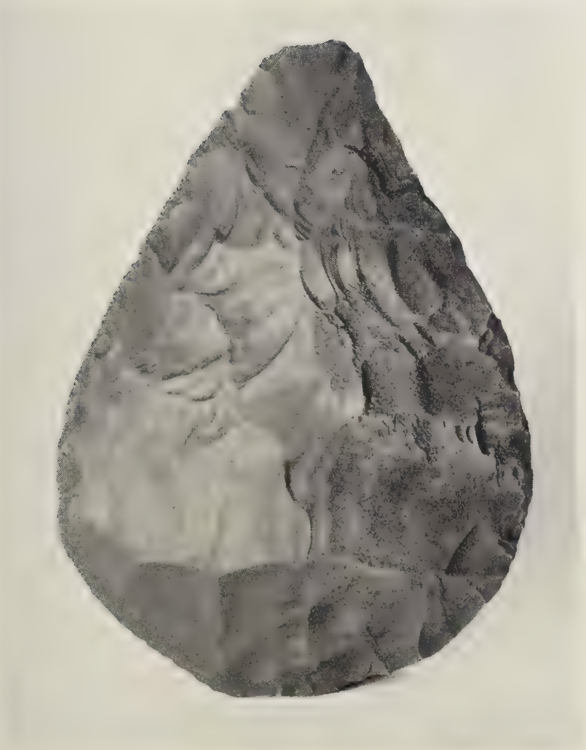


FIG. 60.—Hand ax of flint found by the author near Mutallah, headwaters of the Jordan, Palestine. Of finer workmanship than that in Figure 59. Acheulian Epoch (Paleolithic Period). Photograph by the author. About 2/3.

lithic Period made no great advances over their predecessors. They possessed an improved technique, which is seen in the character of their flint cores or nuclei, and well-formed scrapers and points with carefully retouched margins; but so far as we have been able to ascertain, they did not go beyond the making of secondary tools—that is to say their secondary tools served directly an ultimate purpose and were not used for the manufacture of further, or tertiary, tools.

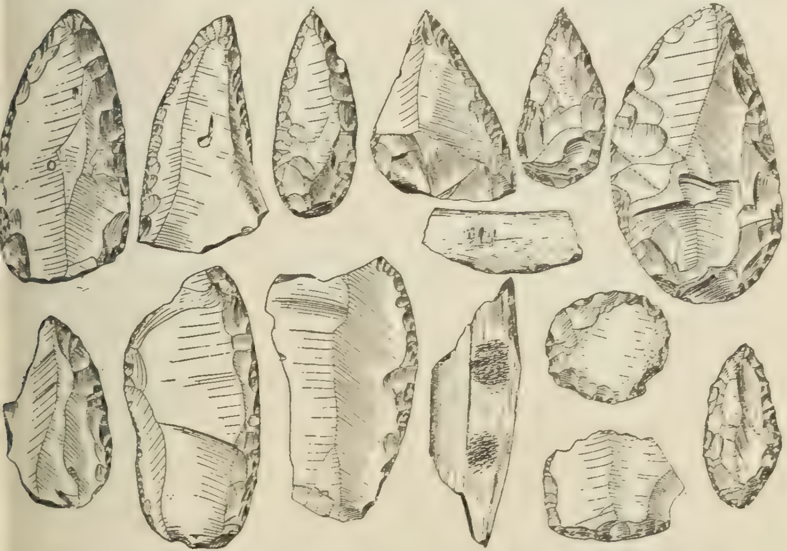


FIG. 61.—Flint scrapers and points retouched on one face only; two bone compressors. Rock shelter of La Ferrassie (Dordogne), France. Mousterian Epoch (Middle Paleolithic Period). After Capitan and Peyrony. About 2/5.

It was reserved for the Upper Paleolithic Cro-Magnon races to inaugurate a new era. This was made possible

---

German and non-German prehistorians, of leaving out the "h," would it not be wise for English and American authors to follow suit, thus avoiding the danger of pronouncing the last syllable "thal" with an "h" sound, instead of "tal" as it should be pronounced as well as spelled?

through improvement in preparing flint cores from which long slender blades could be struck. Then came important additions to the stock of secondary tools (various forms of the engraving tool, small knives, and awls) which enabled them to make extended use of bone, ivory, and reindeer horn, leading to two capital results—the invention of a set of tertiary tools and the dawn of the fine arts.

Cro-Magnon culture was very early transformed through the addition of the secondary shaping tools produced from blade-like flint flakes, without which it would have been impossible to make an array of tertiary tools, such as the bone needle, the javelin point of bone, ivory, or reindeer horn, the javelin shaft, the dart or javelin thrower, and the harpoon of reindeer horn; nor would the Cro-Magnons have been able to embellish their dart throwers and satisfy a rapidly developing artistic sense by producing various objects of art and personal adornment.

From the ancestral tree-dwelling stage of the Tertiary Period to the maximum of the last cold phase of the Ice Age—well along toward the close of the Quaternary Period—is a far cry, not only from the point of view of elapsed time, but also from that of physical evolution. The time required was a million years, more or less. What are the results? In the physical domain, we have development in vision—an overlapping of visual fields leading to a clearer, keener sight. Man has also assumed an erect posture. His brain has become worthy of wielding that marvelous tool, the human hand, made increasingly adaptable through the freedom gained when man assumed an erect posture and when he exchanged tree-dwelling for earth-dwelling habits.

Culturally the sum total of human progress, up to and including the Neandertal or Mousterian stage, does not seem to bulk so very large. Man was still a newcomer on the face of the earth, which remained a trackless waste filled with wild beasts more powerful than he. His energies were consumed in a perpetual struggle for mastery over his environment. If he persisted in the use of natural tools and weapons, it was for lack of time in which to practise and develop craftsmanship in making artificial ones. No wonder that he never got beyond the making of secondary tools such as the combination scraper and knife, the hand ax of flint, pointed implements of stone, bone, and wood.

Although not an artist in the strict sense of the term, man had reached a point while still in the Neandertal or Mousterian stage which gave unmistakable promise of greater things to come. Some of the hand axes and combination scraper-knives of flint he has left to us had already reached the limit of achievement along those lines. He was also a mighty hunter, made use of a simple language, and had taken the initial steps toward the taming of fire. There is certainly no reason, culturally speaking, why we of the twentieth century A.D. should be ashamed to claim kinship with and acknowledge indebtedness to that sturdy pioneer stock.

The Cro-Magnons

Let us now turn from a really primitive culture to the new race which appeared above the horizon some fifty thousand years ago. Part of England, all of Fenno-Scandia, Holland, northern Germany, and a large part of Russia were still under the last of the continental ice sheets. Switzerland and most of the Tyrol were also buried beneath the ice. But practically all the rest of Europe was inhabitable; northern Africa and southern and western Asia must have been much more inviting, climatically speaking, than they are now. The Cro-Magnons obtained possession of the greater part of this territory. Physically they were not unlike the races which succeeded them and those which were living at the dawn of the historic era. They were masters of an improved technique in the preparation of flint cores and had added to their kit of secondary tools those which made it possible not only to make tertiary tools but also to produce works of art such as figures in the round, in relief, engravings as well as drawings, and frescoes—the latter done on the cavern walls, some in one color, some in many.

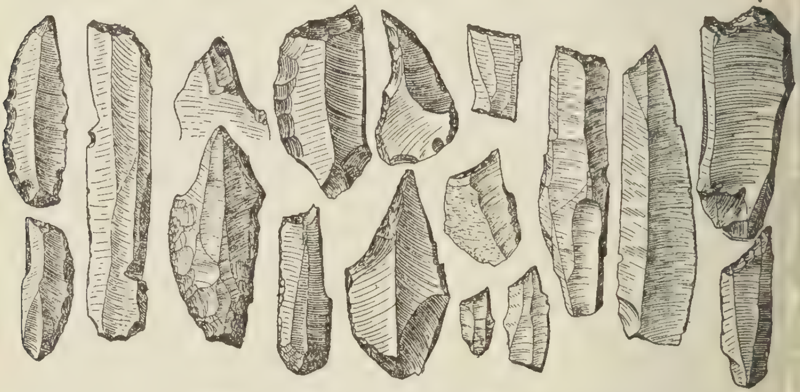


FIG. 62.—Flint gravers from various French sites. Aurignacian and Solutrean Epochs (Upper Paleolithic Period). After Breuil. About 2/5.

The evolution of the fine arts, beginning in the Paleolithic Period, is one of the outstanding phenomena not only of that period but of the entire prehistoric era. It is true that cave art helped to satisfy the exuberant demands of the cave man's artistic impulses, his love of ornament, and his sense of the beautiful; but it was called forth to meet even a greater need: that of religious expression.

Placed in the hands of a sort of priesthood, might not carved or drawn figures be made to help in accomplishing that which otherwise would be impossible? This art epitomizes man's inborn desire to control unseen and magic forces for his benefit. In his hunter stage of civilization, the multiplication of game animals and success in the chase meant everything. Control over animals especially harmful to him also meant much. The religion of the caveman may be distinctly read into the art of the period.

In a study of cave art, one is impressed, although not surprised, by the extent to which it reflects the animal life of the times. To the hunter, game animals would naturally make the strongest appeal to the senses, and would therefore be the first to find expression in his art; among the animal forms reproduced in Paleolithic art, game animals occur much more fre-

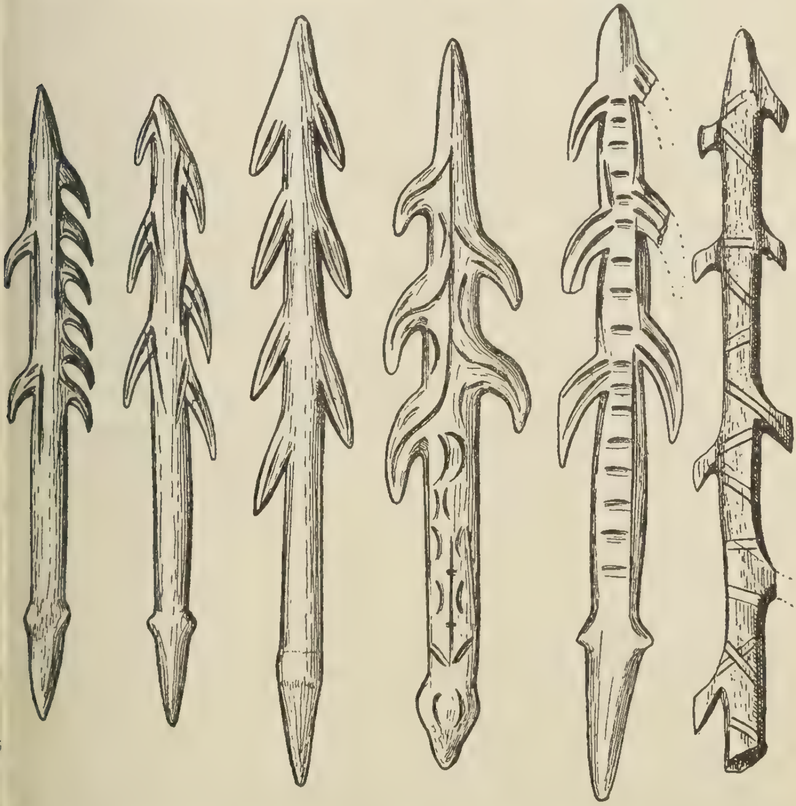


FIG. 63.—Harpoons of reindeer horn from France and Switzerland. Upper Magdalenian Epoch (Upper Paleolithic Period). After Breuil. About 2/3.

quently than any other kinds. The horse and the red deer far outnumber such animals as the hyena and the lion. To one beast killed because it was dangerous to man (or to the animals on which he fed) are pictured scores of game animals captured. Besides, many of the representations are prayers for the increase of the species useful for food, and these account, in part at least, for the preponderance noted above.

The cave artist not only was partial to such species as the horse and the red deer, but he also seems to have had a preference for the female of the species. In some species sex distinction is much more pronounced than in others. The stag can be distinguished from the hind by the presence of antlers; figures of the hind far outnumber those of the stag, a fact which is significant. The hind is the symbol of fecundity; the larger the number of hinds, the greater the increase of the herd. With the horse it is difficult for the artist to differentiate between the sexes; were it not so, we would probably find a like majority of mares over stallions. The same preference holds good among representations of man, no doubt for kindred reasons.

Mesolithic Culture

The rather sudden eclipse of art at the close of the Paleolithic Period is a phenomenon not yet wholly capable of a complete explanation. With the disappearance of art, the reindeer, mammoth, and woolly rhinoceros also disappeared from western Europe. Implements previously made of reindeer horn also ceased to be used or were made of some other material. For example, the harpoon was carried over from the Paleolithic to the Mesolithic, but it was made of stag horn instead of reindeer horn and on slightly different lines. Wholly new features appear, one of the most striking being the so-called painted pebbles which have been found in considerable numbers especially in the Pyrenees at Mas d'Azil. This staion has given the name Azilian to an early phase of the Meso-ithic Period.

The Mesolithic peoples did little more than to serve as a ink in the chain of human evolution. No great or fundanental achievements can be attributed directly to them, alhough some prehistorians give them credit for what was acomplished during the shell-heap phase. The shell-heaps or itchen middens are refuse heaps consisting of shells of edible nolluscs, fragments of animal bones which served as food for prehistoric man, and implements made of bone, horn, and stone. When these heaps were first observed, they were thought to be natural formations, but investigation showed not only that they were artificially constructed, but that they held many secrets of the life of prehistoric man.

It is true that the first definite traces of pottery were found in the shell-heaps; the ceramic industry was however still in its infancy. Initial steps in the mining of flint and in the domestication of animals and plants were also probably taken by the Mesolithic races, but it was reserved for Neolithic man to realize the possibilities of these great economic factors in cultural evolution.

NEOLITHIC CULTURE

It was a great step forward when man found other and surer ways of controlling the food supply than the hazards of magic as practised during the cave art period. Paleolithic man was never more than a food gatherer; Neolithic man became a food producer as soon as he began to cultivate plants and domesticate animals. With the development of these new industries, fixed abodes not only became prerequisite but also were more easy of attainment through the newly acquired ceramic and textile industries.

One of the far-reaching results of the domestication of animals was the use of certain of them, especially the horse and ox, as beasts of burden. Both the horse and ox became draft animals as early as the Bronze Age, before the close of which the horse was also employed as a mount. Civilization is measured roughly by the draft man makes on raw materials; to exploit and transport these requires the expenditure of labor. Down to about the beginning of the Bronze Age, the only kind of labor man knew how to exploit was human; the demand for it led to human slavery. The commandeering of the horse and ox as beasts of burden relieved the situation and eventually became a powerful factor in doing away with human slavery, especially after improved methods of applying animal motive force to the load were introduced about the tenth century A.D.

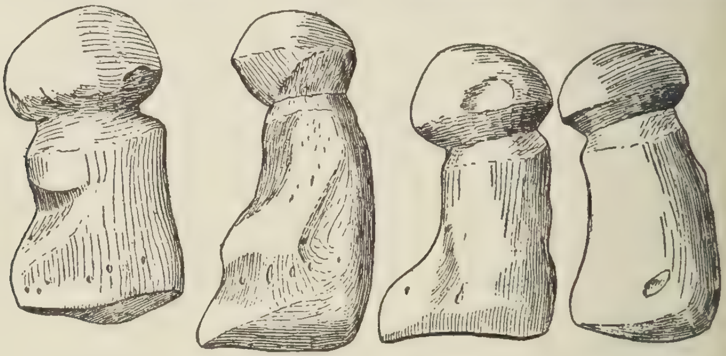


Fig. 64.—Metacarpals of the mammoth converted into human statuettes. Loess station of Predmost, Moravia. Aurignacian Epoch. After Breuil. About 1/4.

The monotony of the food supply prior to the Neolithic Period seems appalling when compared with modern standards. In Switzerland during the last interglacial epoch it was 90 per cent cave bear; in Moravia during the last glacial epoch it was 90 per cent mammoth; in Denmark during the Mesolithic Period it was 90 per cent shellfish. The Neolithic races changed all that. While by no means despising the products of the chase, they no longer had to depend on them. When game was

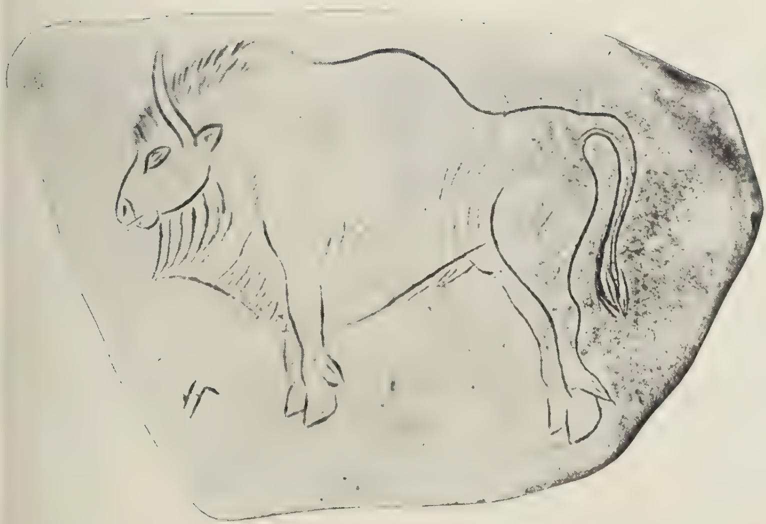


FIG. 65.—Bison incised on limestone. Rock shelter of Laugerie-Basse (Dordogne), France. Magdalenian Epoch. 1/1.

arce they turned to their own domestic flocks. To fish, flesh, nd fowl were added garden products in their season, and eans were found for storing cereals both in and out of season.

Although mankind had practised a stone industry for untold ges, Neolithic ingenuity made it possible to produce new types f stone implements. To the chipping process, they added ecking and polishing as shaping processes. Progress in min- g made it possible to tap new sources of the highest quality int.

The textile art is another of the great Neolithic acquisitions. included knitting, spinning, weaving, embroidery, and the aking of nets and baskets. By reason of the perishable na- ure of the materials employed, prehistoric examples of the xtile art are extremely rare. The best preserved examples are ose found in the pile villages of Switzerland, villages built ver the waters of lakes or near their shores. The pile vil- gers employed both flax and wool. Silk and hemp were un- nown in Neolithic times. Very little is known of the number nd kind of garments worn by either sex during the Neolithic eriod. Wooden instruments for breaking flax and wooden ombs for combing it have been reported from a number of wiss stations.

The earliest pile villages of Switzerland belong to the last ird of the Neolithic Period. The walls of the houses were omposed of upright slabs. In some cases the houses were built irectly on the moors without the pile substructures. The round plan of a house was rectangular and provided for an ncovered platform, a combination workroom and kitchen with earth and handmill, and a combination living- and bedroom ith fireplace, loom, beds, etc. The building material included ak, beech, and birch. The so-called block house of the log abin type did not appear until the Bronze Age.

The art of navigation can be traced at least as far back as the eolithic dugout boat, carved from the trunk of a tree, usually oak. The shaping of this primitive vessel was done by means of stone implements and the use of fire. The wheel which revolutionized the art of transportation by land was probably put to limited uses before the close of the Neolithic Period. The first wheels were obviously sections from tree trunks. The second step came when wheels were made of more than one piece of wood with as much of the inner portion cut away as possible in order to decrease the weight. A later and better method of making the wheel light in weight was the use of spokes, but this change could hardly have taken place prior to the appearance of the metal tire.

The beginnings of the healing art are obscured, if not lost, in the mazes of the Stone Age; they may antedate the Neolithic Period. Many of the charms, amulets, and talismans no doubt have to do with prehistoric curative and preventive practises. So far as internal medicine and the healing of flesh wounds are concerned, practically no evidence has been preserved. Fortunately the case is different when it comes to the surgical operations which affect the bony framework. There is convincing evidence that Neolithic man practised trephining with a considerable degree of skill and success. This was an operation performed to relieve depressed fractures, to remove diseased bony tissue, and to cure such maladies as epilepsy and convulsions of various sorts. It can be traced without a break from modern surgical practice back at least to early Neolithic times; its great antiquity is matched also by the boldness which led to its inception.

THE BRONZE AGE

Some of the greatest discoveries of all time have been by accident. The reduction of metals from their ores probably belongs in this class. Metals are especially prized for their tenacity, ductility, and fusibility. Copper, gold, iron, and silver in their native state were the first metals to attract the at

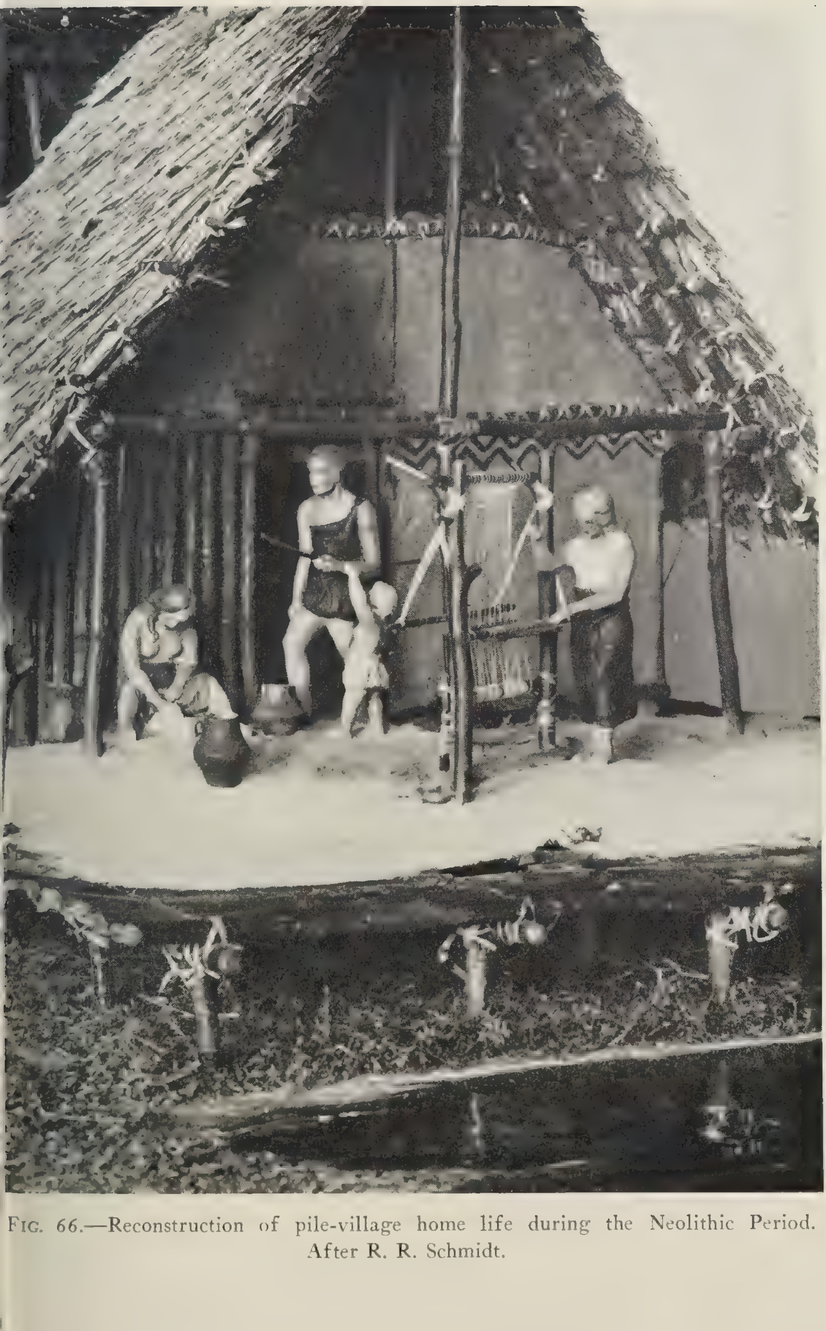
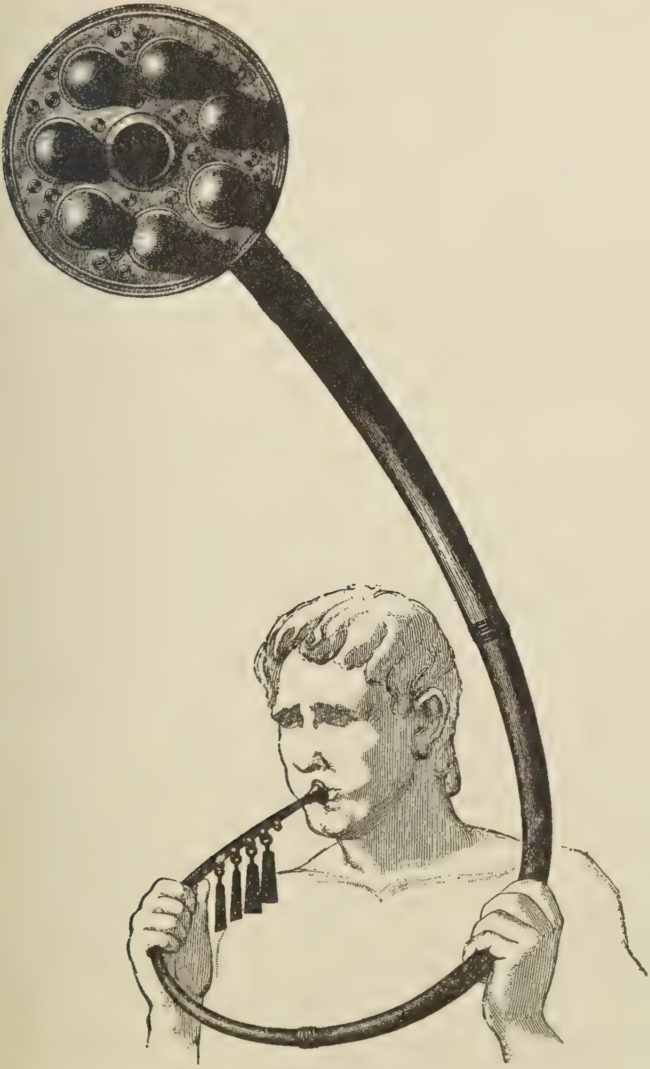


Fig. 66.—Reconstruction of pile-village home life during the Neolithic Period. After R. R. Schmidt.



G. 67.—Bronze trumpet. Many of this type have been found in the peat bogs of Denmark. Bronze Age. After Hammerich.

tention of prehistoric man. Very little progress toward an Age of Metals could have been made by the Neolithic races so long as they were dependent on a knowledge of, and the supply of, native metals alone. The new era was not ushered in until the discovery of the art of extracting metals from their ores and of melting and casting them.

When by chance a lump of copper carbonate, tinstone, or hematite was used as one of the circle of stones surrounding the hearth and had become embedded in its embers, the lump would almost certainly be reduced to metal. Such a mass of metal would attract the attention of primitive man and experimentation would soon disclose its properties of malleability and toughness, qualities destined to prove of great utility.

The earliest production of copper from its ores probably took place in Cyprus where vast piles of ancient slag are seen in many localities. Cyprian copper was sought after in Homeric times, and sent as tribute to Egypt at a still earlier period. The first metal artifacts were of copper unmixed with tin; then came objects of bronze which is an alloy of copper and tin. The art of casting bronze objects was one of the notable achievements of the Bronze Age.

The change from the Stone Age to the Bronze Age took place without the least break. Thus the important fortified Neolithic villages continued to be occupied after the introduction of bronze. The Bronze Age pile villages are farther from the present shores of the Swiss lakes than are those of the Neolithic Period, but this is due to the change from a moist to a dry climate. Bronze Age population continued to live in simplicity, their principal architectural structures being for religious purposes as was the rule with their Neolithic predecessors. The megalithic monuments, so-called because usually built of large stones, belong to this class. The various types o megalithic structures are known in Brittany as dolmens, me rs, cromlechs, and alinements, the dolmen and menhir being ie fundamental forms from which the others are derived.

THE GROWTH OF COMMERCE

The lengthening of the radius of man's needs received a re-arkable impetus with the discovery of metals; these in them-lves became not only an article of commerce, but also soon rved as a means of facilitating commerce in products of every nd. Pack and draft animals came into use. The appearance the wheel as an ornament and with objects of a ceremonial iaracter leads to the conclusion that it likewise served other id more practical purposes. Votive ships and chariots, domi-int cultural symbols of the Bronze Age, are further evidence the life of the period; both are linked with sun worship, hich is preëminently the religion of the agriculturist and rdsman.

With the growth of commerce Europe became a unit, in-istrially speaking. Evidence of considerable traffic in copper gots among countries bordering on the Mediterranean is not cking. Amber and salt were products in which there was tensive barter. Media of exchange, usually in the form of etal rings or axes, and systems of weights and measures were eveloped as aids to commerce.

THE IRON AGE

Iron seems to have come into use as early as 1,300 B.C., both Egypt and Mesopotamia. At about the same date, iron be-an to be extracted from the ore on the southwestern shores of ie Black Sea under the rule of the Hittite kings. The begin-ing of the Iron Age in Italy is placed about 1,000 B.C. and in estern and northern Europe at still later dates. It lasted until he historic era and the Age of Steel.

The oldest painted pottery and glass vases in western Europe, including Germany, date from the first or Hallstatt Epoch of the Iron Age. The Hallstatt Epoch witnessed an important change in the art of making knives; at the type station of Hallstatt were found knives with articulating iron blades which could be shut in bone handles and carried in the pocket, a form persisting to-day in the ordinary pocket knife. The first appearance of shears, similar to our modern shears was not until the second or La Tène Epoch of the Iron Age. The first use of the potter's wheel in western Europe also dates from this epoch. With the increase of wealth and means of accumulating it, the need of locks and keys became acute. If such means of security existed prior to the Epoch of La Tène, they were probably simple wooden devices that have decayed leaving no trace. The iron key was in common use north o the Alps during the last century B.C.

Present Problems

One of the big problems in European prehistory is the correlation of human cultural and skeletal remains with the various phases of the Ice Age. Glaciologists have combined with prehistorians with the result that at least a good beginning ha been made toward referring stations of the Old Stone Age to the various glacial and interglacial epochs. In brief, Reid Moir and Breuil, who have recently given much attention to this subject, would correlate the Pre-Chellean and Chellean with the Günz-Mindel, or the first interglacial epoch, and the Acheulian with the Mindel-Riss (second interglacial). This would place the long warm phase of the Mousterian Epoch in the third interglacial or Riss-Würm Epoch, and the cold Mousterian, Aurignacian, Solutrean, and Magdalenian in that which remains of the Ice Age, namely the advance, maximum, and retreat of the Würm glaciation.

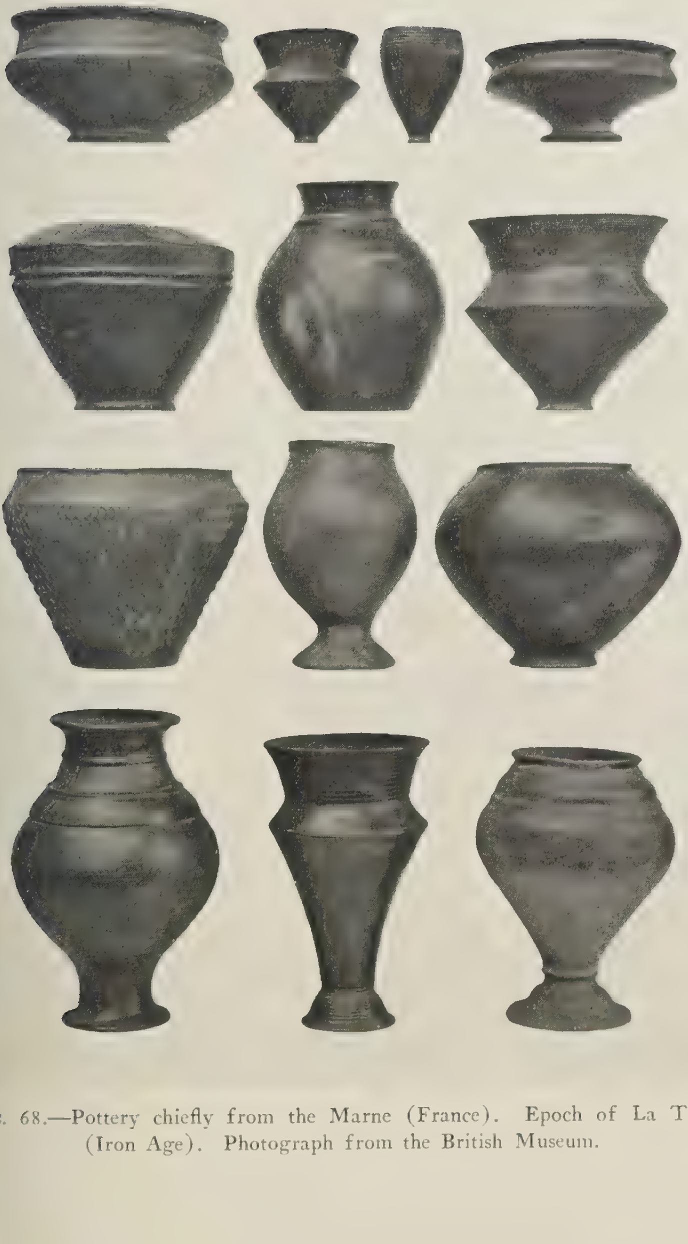


FIG. 68.—Pottery chiefly from the Marne (France). Epoch of La Tène (Iron Age). Photograph from the British Museum.

If Breuil is right man began to live in caves much earlier ian was supposed; for he would refer the industry at the base f the relic-bearing deposits from the grotte de l'Observatoire Monaco to the Pre-Chellean Epoch. Even Boule who is ulaconservative would class the oldest industry from the Obrvatoire station as Chellean.

It should not be inferred that man lived in Europe only durg interglacial epochs; even during the maximum of each of ie four glaciations there was always room left for man to aintain a foothold. Breuil definitely refers the Paleolithic ation of Coomb Rock, England, to the Riss Glacial Epoch. or the culture of this Epoch and the succeeding Riss-Würm iterglacial, he would coin a new term "Levalloisian" to be inrcalated between the Acheulian and the cold Mousterian. reuil considers the Lower Boulder Clay of England to be the oduct of the Mindel glaciation and the Upper Boulder Clay be that of the Riss glaciation.

The Paleolithic and Mesolithic cultures of Europe have been ore completely studied than have those of the Neolithic and ie Age of Metals. This is partly due to the fact that the roblem has been simpler. In spite of difficulties encountered, ur knowledge of the Neolithic is yearly becoming better deied. This progress is due in large measure to the Scandinaans, the Swiss, and the Germans, although credit must be ven to practically every other nation for a share in it. In ite of all that has been done there is still no well-defined ironology of the New Stone Age that will apply to anything iore than restricted regions. It remains to be seen whether ich a chronology and terminology can be determined that can ver satisfactorily the whole of Europe. No one has as yet sen to become the arbiter of Neolithic chronology; perhaps ie time may not yet be ripe for such a consummation. In this eld the geologist and paleontologist can be of little service to ie prehistorian. Besides, the very complexity of the problems to be solved has put a damper on initiative. What is true o the Neolithic is also true of the Bronze and Iron Age Enough however is being done to prove that the problems a not insoluble. The intensive work that is now going on wi prepare the way for works of a comparative nature and eventually make possible a wider correlation of the culture of one r gion with those of its neighbors.

One of the hopeful signs of the times testifying to an abi ing interest in prehistory especially of Europe and the Ol World in general is that three institutions have recently bee incorporated to do work especially in this field. I refer to th *Institut de Paléontologie Humaine* in Paris, the *Urgeschich liches Forschungsinstitut* at Tübingen, and the *America School of Prehistoric Research.* All three are needed t supplement the activities of preëxisting universities, museum societies, etc. It is also perhaps worthy of mention in this co nection that, at the meeting of the British Association for t Advancement of Science in Glasgow last September, of th thirty papers which were read before Section H. twenty-thre or over three-fourths, were on the subject of Old-World pr history and fifteen, or exactly half, on European prehistory

The major and pressing problem before the prehistorian to increase our knowledge of the prehistory of Asia and Afri in order that correlation of Old-World prehistory as a who

---

[5] An even better indication of the lively interest taken in European prehisto is the ever increasing volume of the current literature, both technical and pop lar, on the subject. Perhaps the most significant example is the *Reallexikon d Vorgeschichte,* the first volume of which appeared in 1924 and of which the fi two numbers of volume XIV have just been issued from the press. The fi volume of IPEK—*Jahrbuch für Prähistorische und Ethnographische Kun* (Leipzig) appeared in 1925; the *Vorgeschichtliches Jahrbuch* (Berlin) in 192 and *Antiquity* (Gloucester) in 1927. Max Ebert is editor of the *Reallexikon* a the *Vorgeschichtliches Jahrbuch;* Herbert Kühn, of IPEK; and O. G. S. Cra ford, of *Antiquity*. The first memoir in the series entitled *Archives de l'Instit de Paléontologie Humaine* appeared in 1927 and since then three more memoi of the series have been issued.

may be achieved. To this end, the American School of Prehistoric Research has obtained permits and is already exploring and excavating jointly with the British in Iraq, Palestine, and Transjordania.

The campaign of last autumn was highly successful. The area explored was the region of Sulaimani, about 160 miles northeast of Bagdad. Many caves and rockshelters were located. A small cave at Zarzi proved to be exceedingly rich in remains belonging to the Aurignacian Epoch (Paleolithic), the principal types being exactly comparable with those from Aurignacian stations in the Danube valley, lower Austria, and south central France. Another interesting feature is that at the top of the deposit this typically Aurignacian culture grades off into the microlithic Tardenoisian (Mesolithic). In other words, remains of what would be the two intervening epochs in Western Europe, namely, the Solutrean and Magdalenian, are lacking. The industry from Zarzi does not seem to have anything in common with the Capsian industry of northern Africa.

The expedition excavated in part a great cave at Hazar Merd, known locally as *Arshkot-i-Tarik* or "Dark Cave." This they found to contain a typical Mousterian industry belonging to the epoch immediately preceding the Aurignacian. Above the Mousterian level there were a few scattered implements of the Zarzi, i.e., Aurignacian, type and at the top of the section an abundance of pottery was found. It would seem, therefore, that both the Mousterian and the Aurignacian cultures form a zone stretching across both Europe and Asia. Whether the prehistoric current which carried these cultures moved from west to east, or the reverse, is a problem which may be solved through further exploration.

CHAPTER X

SOCIETAL EVOLUTION

ALBERT GALLOWAY KELLER
PROFESSOR OF THE SCIENCE OF SOCIETY, YALE UNIVERSITY

The essence of evolution is the development of form out of form, in a connected series, with survival of the fitter forms in adjustment to environment. The outcome of evolution is adjustment of life to life-conditions. No informed person feels any longer the need of arguing the truth of the theory; interest now centers in the extension and correction of knowledge as to the details of the process, and in the applications of the truths discovered. In the Darwinian theory of adjustment we have one of those widely orienting factors which array knowledge in orderly vistas and lead mankind to believe that there is some sense in earthly existence.

If there is any one place rather than another where mankind would like to find sense and order, it is in the field of human social relations. No one can read the vivid pages of Henry Adams's *Education* without a deeper appreciation of the darkness and deviousness of the ways along which all of us are traveling, though most of us are not so conscious and concerned about our gropings as was that anxious and rueful searcher after enlightenment. Adams, an evolutionist believes, was after too much. He wanted to find some norm of progress in human history, and seems to have renounced high hopes of Darwinism when he found that it offered no such norm.

It is one of the common misconceptions about evolution, and one into which Adams fell, that it means progress. It means adjustment only. Such adjustment seems to be progressive if it leads in a direction which we choose to call forward; but it may appear also to be retrogressive if its runs counter to that direction. To us the change from the flint-lock to the percussion-cap musket seems a progressive adjustment, and the return from the latter to the former, in hot and damp regions, where the cap deteriorated while the imperishable flint did not, appears to be retrogression. Both were expedient adjustments to life-conditions.

We ought not to be dismayed at the sight of forces operating in what seem to us opposite ways, at one and the same time. We should not bemoan the failure of evolution because motion is not always visibly in the direction we like or expect, any more than we should despair of gravitation because it causes both the stone to fall and the balloon to rise. The fact is that the terms progress and retrogression, as their etymology indicates, imply that the user of them has selected some center of operations from which he can infallibly adjudge what is "pro" and what is "retro." He is at liberty, in free countries, to do this for himself and to try to persuade others that he is right; and sometimes whole groups can agree on what is progress and what is not; but it is generally impossible to get extended unanimity as to the identity of "forward" and "backward." Especially is this the case when it comes to the appraisal of social relations, institutions, and policies.

But this whole difficulty is escaped, in the case of evolution, if we consent to view that process as it is, and do not, in our straining after the assessment of things as progressive or retrogressive, hug to ourselves the misconception that evolution and progress are synonymous. If we simply ask, concerning any organic or social form, whether it is an adjustment, past, present, or pending, we shall all find ourselves in a substantial agreement that will permit of our going along farther together. I myself think the protective tariff to be a case of retrogression, but that does not prevent me from agreeing with its many ardent and even candid sponsors that it is an important adjustment to life-conditions. I regard the League of Nations as the only practical and working proposition in the field of international relations; others think it a foolish and retrogressive measure; but all of us could agree that it is a widely accepted adjustment, now under test. Slavery was once an adjustment that everyone believed in. The time came when conditions changed and there arose a difference of opinion as to whether it was good or bad, progressive or retrogressive. Now it has come to be regarded as a maladjustment. But, whatever the judgment upon it at various times, anyone can see that it has been one of the ways into which men naturally fell in meeting the conditions of life as presented.

I have used, perhaps, a disproportionate amount of space in seeking to enforce this point; but I have done so deliberately, because there is no other range in which people are so wont to set up private and local standards, upon which they then assess all things, as they are in the range of social life. If many are disposed, petulantly or dismally, to despair of organic evolution because it does not support their ideas of progress—which it never set out to do, any more than it advertised to explain the origin of life—how much more darkly would they despair of a social evolution that lays no claim to be progressive. Man's dearest interests are vitally involved in his social life; in fact, what discouraged Adams and others with Darwinism was not its givings in the organic field, but its fallings-short, in promise, of their hopes in the social field—into which it was speedily and incontinently dragged by the almost instinctive tendency to "reason from analogy."

I cannot go into this last matter—of how conclusions were drawn concerning the nature and life of human society from the nature and life of organisms. It was partly Darwin's fault for embarking upon the discussion of social and moral matters, in the *Descent of Man;* matters concerning which he was little better informed than any other non-specialist. It was still more the fault of Spencer, who became so enamored of the analogy between organism and society that he came almost to believe it an identity. Then the Germans got hold of it and constructed huge volumes of uninspired muddlement about the "structure and life of the social body."

The analogy between a society and an organism is a pretty one, as developed by Spencer. Its development was not without use. But of what use? It is of no use at all in proving anything about society. An analogy is no proof of anything. Consider the exhorter who described the life-cycle of the butterfly and wound up triumphantly: "Now who shall say that there is no proof of immortality!" Proof demands facts, ever more facts, all sorts of facts bearing on the subject. Out of them comes the theory, and from them the theory is corrected and re-corrected. It is most essential that the facts shall not be selected, either to be acclaimed or to be ignored.

An analogy, on the contrary, is a specially selected fact or relation. It is picked out of many possibilities because it is thought most vividly to set forth some idea already developed and fixed in mind. It is not the search for truth that the analogy-user is after; it is the exposition of a position already taken. Analogy is perhaps the most effective device for exposition; but it is the tool of the preacher, not of the discoverer. Its supreme effectiveness is found, probably, in the parables of Christ,[1] who, in trying to transmit spiritual truths to simple minds, took recourse to homely analogies on all sides.

There can be no direct "reasoning from analogy," therefore. People who write on social evolution are regularly charged with trying to do that, and generally justly; perhaps if a writer starts out by saying that it cannot be done, it will be believed by some of his readers that he is not endeavoring to do it.

---

[1] For example, Matt. xiii., 31, 33.

But the analogy, correctly understood and not burdened with a weight it cannot carry, can perform a service of great value. If in one field of investigation (say the organic) we know that certain phenomena are produced in a certain way, and if in an adjacent, less understood field (say the social) we find analogous phenomena, we are justified by long experience in the inference that the unknown producing factors in the new field are probably similar to the known ones in the older range. If, in particular, we find adjustments in the organic field produced by the so-called Darwinian factors, and if we discover that the social range shows social forms representing adjustments to the life-conditions of society, it is reasonable to infer that the factors producing social adjustments may be similar to those producing organic adjustments. This is the more likely in view of the fact that all members of human society are organisms, so that the two ranges—of organic and of social life—are not merely contiguous, but interpenetrative. If organic forms are evolved by the action of the Darwinian factors of variation, selection, and heredity, their joint action resulting in adjustment to life-conditions, it is a hint to us that, in default of any more promising lead, we had better look for counterparts of the Darwinian factors in the social range.

This suggestion has been unreflectingly and unconsciously adopted in popular usage. It is seen that habits and customs are passed on from generation to generation somewhat as bodily qualities are. It is necessary to use some term to cover the process. The biological term is heredity. It is easier to catch up a term in use than to invent a new one. Hence writers speak of "social heredity." It is like speaking of "brass andirons." However, it is vaguely realized that habit and custom are not transferred by actual heredity, through the germ-plasm; and the perception of the unanalyzed difference involved is indicated by the adjective "social"—not plain "heredity," but "social heredity." The upshot of the matter is that even the casual observer has noted the likeness between things social and things organic and biological.

It seems to me that we had better take this hint from analogy and work on it. Evolution is proved and accredited in the organic field; at Darwin's centenary scientists of all descriptions united, in a volume called *Darwin and Modern Science,* in bearing witness to the fruitful suggestion received by them from the Darwinian theory. We had better see whether that theory can not help us in discovering some order and sense in social phenomena. I think it has helped some of us in just that way. Our courses in the science of society, representing the best we have to give to our students, have for many years begun with the effort to make sure that they all secure a layman's knowledge of organic evolution.

My predecessors in this course of lectures have shown that the evolutionary process does not stop short of man as an animal. Huxley,[2] in comparing him with the anthropoids, summarizes as follows: "Thus, identical in the physical processes by which he originates—identical in the early stages of his formation—identical in the mode of his nutrition before and after birth, with the animals which lie immediately below him in the scale,—man, if his adult and perfect structure be compared with theirs, exhibits . . . a marvelous likeness of organization. He resembles them as they resemble one another—he differs from them as they differ from one another." But if man is thus similar to the animals, it would appear that he must come under the same need of physical adjustment to life-conditions. If so, he should show differences comparable to those exhibited by animals as the result of adjustment to widely diverse life-conditions. Being the most widely ranging of all animals, he might be expected to show the greatest physical diversities. He does not. Does this mean that evolution stops short of man? Let us first get some of the facts before us.

---

[2] Huxley, T. H., "Man's place in nature," 1901, p. 83.

Human beings are much alike over both time and space. For many thousands of years man has been substantially the same kind of a physical being as he is to-day. Over all the earth he is pretty much the same sort of animal. One who has followed the efforts of scientists to distinguish the varieties, or races, of mankind can realize how essentially alike they are. Conviction of this essential similarity has led to the assertion that "man is unchanged in a changing environment." But this seems to mean, on the face of it, that somewhere during the course of human development evolution is suspended; for evolution is adjustment to environment.

Certainly mankind has encountered widely diverse environments. Men live in countries where the temperature falls far below zero; also where it rises considerably over one hundred degrees Fahrenheit. They inhabit regions which are cold and dry, cold and damp, hot and dry, and hot and damp. They live at sea-level or thousands of feet above it. They persist where there is much animal life of all kinds, or where there is little of any kind. Of all animals the most widely distributed over space, men have encountered all varieties of earthly environment. Yet they are essentially alike. The most widely distributed; the least changed—"unchanged in a changing environment."

Through time also, with its secular and often radical changes of life-conditions, alteration in man's physical make-up has been relatively slight. Animals adjust even to so regular and recurrent a set of conditions as the succession of the seasons, while man has remained practically the same through the protracted ups and downs of centuries and millenia. Is it possible that the evolutionary process is stayed and that man is exempted from it? Of course it is not halted; and he is ot exempt. The process merely changes its mode. It is no nger evolution of the organic type, resulting in structural djustment; it is evolution of another grade, resulting in nother sort of adjustment. There must be adjustment just he same, as a condition of existence. Evolution goes on as ng as adjustment to immutable life-conditions goes on—that s, as long as life lasts. It is this typically human phase of volution which we want to identify and examine.

When human beings get into a situation (a cold climate, for nstance) which, for animals, evokes physical adaptation (such s a thicker coat), we find, perhaps, some small adjustment y way of bodily change; but typically and generally what we ee is the employment of materials external to the body—skins, vood, metal—which are interposed to form the instruments f adjustment. It takes a certain brain-action to arrive at uch utilization of the things available in nature. When bees uild combs, it is by an instinct that represents a single adjustnent, once and for all, whereas man has, in the brain, a sort f specialized adjustor capable of being turned upon this and hen upon that situation. His brain is somewhat like one of hese tool-handles which include in one instrument the possiility of a variety of operations, except that the brain is ininitely more protean in its transformations.

The brain clothes its adjustments in material form. They re thus realized or made real—materialized, or rendered in erms of matter—externalized, or worked out in things exernal to the body. Every such realized thought is a piece of ulture or of the apparatus of civilization. Such are the limbing-irons of the linesman, which are the cultural counterart of the natural climbing-foot; such is the aëroplane, as ompared with the wings of the bird. Tools, weapons, houses, arachutes—all these are objects of material culture which are ounterparts of what nature has developed over countless ages f organic evolution—for the beaver, whose tools are teeth;

for the stag, whose weapons are hoofs and horns; for the nautilus, whose house is his shell; and for the dandelion seed, which sails about on its supporting structure.

But not all these cultural products are made of substances. They are often immaterial forms of organization and conduct. Specialization of labor is a cultural adjustment for readier self-maintenance, saving as it does time, effort, and material, and yet winning to a better product. Marriage is a cultural adjustment by which two very differently endowed sexes get along together and rear young. Government is a cultural adjustment resulting in orderly and peaceful human relations. All economic, political, and other social systems, economies, and institutions are cultural adjustments to life-conditions of maintenance and sex, and of others presented to men in their earthly life. Good government is as much a favorable adjustment as is the web foot of a duck, and polygamy is as obsolete an adjustment for us as five toes came to be for the horse.

If this is so, the fact of adjustment, and the need of it, is as patent in the case of mankind as it is in that of other animals or of plants. Only it is attained, in the former case, by factors not precisely the same as in the latter. We shall come to these factors presently. The outstanding fact, thus far, is that plant and animal adjustments are typically physical, while human adjustment is typically not physical. It is mental.

It is also social. Civilization is the product of numbers and the contact of numbers. The new invention, representing a better adjustment to life-conditions, say the gas-engine, never springs full-fledged out of the brain of any individual. The one who gets the credit for it is at best but the last of a long line of experimenters, who has added the finishing touch—where, indeed, he is not the exploiter who merely appropriates the results of a long series of labors in which he has borne no part. Much less did any individual invent marriage or property, though tradition sometimes accredits them to a mythical

v-giver. To arrive at any of these cultural adjustments de-
ands the give and take, and the gradual accumulation, pos-
le only where there are a number of human beings coöperat-
g in the effort to maintain and perpetuate the race, that is,
a society. Cultural adjustment is therefore social; or,
tter, since the word "social" is so vague, it is "societal."
is a thing that occurs only in society. It is "of society," and
at is what "societal" means. The securing of such cultural
ljustment is, therefore, by "societal evolution."

This is the new mode or grade of evolution that replaces for
an the organic mode or grade. Organic evolution goes but
short way in explaining human relations, even though, since
an remains always an animal, it is basic to the whole of
man existence. Natural selection continues to operate upon
en, for instance, through the ravages of some diseases;[3] but
general it is replaced by another kind of selection which may
called societal. Natural selection could never result in a
ligious adjustment, for example. Such an adjustment is not
the organic grade. At best, natural selection cannot exceed
at grade; in fact, it is a risky contention to assert that even
e fittest human animals are surviving and multiplying in com-
arison with the unfit. The alarmists about race-suicide,
unter-selection, racial degeneration, and the like, are com-
aining that we are breeding all the time from the worse ele-
ents in the population. We may be, if animal-fitness is the
le criterion; and we may be, even though we realize that
ere are other criteria. But it is essential to note that societal
tness—fitness to be a member of society—is not identical with
hysical fitness. It is enlightening to run over a list of those
en who have served society best and see how many of them
ere physically defective.

If natural selection is not effectively in operation in pre-
erving the fittest human animals, because societal criteria

---

[3] Holmes, S. J., "The trend of the race," 1921, chs. VIII and IX.

always cut across organic criteria, it is certainly out of its range when it comes to institutional development. If we read that cannibalism or feudalism has perished by "a sort of natural selection," the very qualification in the phrase indicates that the user of it is merely employing an analogy. We are, I repeat, upon another plane of evolution where the processes and survival-values are somewhat altered from those existing in nature. The attempt to carry natural selection over to the new plane is wholly unproductive.

It is understood, then, that evolution in the societal range is of a different kind, quality, brand, or variety from that operating in nature. Societal adjustments, we go on to infer, are probably produced by the operation of factors present in the organic field, though these factors must needs be somewhat metamorphosed in their manifestations in the societal range. To one who has in mind such considerations as the foregoing, there is nothing to do but to try out the Darwinian factors upon societal phenomena. But upon what shall he try them? Of course, upon the aforesaid cultural adjustments: inventions, systems, economies, organizations, and the rest. Are these societal adjustments, like the structural ones of plants and animals, the end-results of variation, selection, and heredity, operating in their societal modes and manifestations?

A great many of the cultural adjustments are, as we see them in institutional form, as in marriage or religion, immensely complex. It is expedient to seek them in their simpler phases, just as one would reduce a complex fraction in order to be able to handle it. The simplest form of all societal institutions is custom. They all come out of it. Custom is also a conception difficult to handle because it is all-pervasive and eludes the grasp. It required a sort of *tour de force* to seize, define, and thus reduce to usable form this elusive and floating conception. This was done by my predecessor, Professor mner.[4] I am bound to say that he did not give much atten- on to the possibility of extending evolution into the societal ld;[5] but he furnished, in any case, the necessary basis for ch an enterprise. We shall review his findings in their salient pects.[6]

When the first societies of which we know appear to view, ey are already provided with a set of ways, or a traditional ocedure, by which they carry on self-maintenance, and every her of their activities as well. These ways represent a con- rrence of group-members in the practice of expedients, eco- omic, political, religious, or other, which have been proved them, in the event, to be successful ones. These expedient ays have been called the folkways or mores. Language is e of the most typical of the mores; division of labor is nother. No one planned them, but they grew up and are racticed unquestioningly, unconsciously, and automatically. hey correspond to habits in the individual. Taken all to- ether, they constitute the code of behavior in a society. They present the proper way to act, and, even though they are not ubjected to any rational or critical examination, there exists e conviction that they are the only right ways, the only ones t to live by. The mores, says Sumner, are "the popular sages and traditions, when they include a judgment that they re conducive to societal welfare, and when they exert a coer- ion on the individual to conform to them, although they are ot coördinated by any authority." It is just as well to have a echnical term for them, for they are not precisely customs, or ocial habitudes, or ethics, or morals.

They become uniform and universal in a group, and also mperative; and, often over long periods, they are so resistive to change as to appear invariable. Many of them are strongl sanctioned by religion; in fact, practically all of them that a of long standing are supported by the readiness of the spirit ancestral or other, to punish infringement or alteration. Th thus come to form a prescribed body of rules of behavior f life in society that well deserves the title of "the social code.

---

[4] Sumner, W. G., "Folkways," etc., 1907.

[5] Cf. Keller, A. G., "Societal evolution," 1915, pp. 328-330.

[6] Certain of the following paragraphs are a reproduction of Keller, . G., "Through war to peace," 1918, parts of chs. VI and XVIII.

Within the range of societal self-maintenance, the mor determine how the struggle for existence and the competitio of life shall go on, thus rising to meet and cope with certai vital and perennial life-conditions. Another inescapable an vital life-condition is laid down in the bisexuality of the huma race; there are the relations of the sexes to be ordered, in th interest of the society's well-being. Innumerable mores atten upon the association of man and woman, parents and childre and they work out into various forms of marriage and th family. A big group of mores always surrounds some vit condition of society life, like that of sex, and forms the a proved method of dealing with it. Another such condition, fo further example, was felt in the vividly conceived presence o a world of ghosts and spirits, an imaginary environment t which men adjusted themselves by the unplanned developme of a set of mores covering forms of avoidance, exorcism, co ciliation, and propitiation of spiritual beings.

But these several sets of mores, "mere custom" at firs gradually attained a stage of organization where they becam institutions, as, for example, matrimony or religion. Ther is no human institution that has not risen from the matrix o custom; the rise of new institutions, now as always, is ou of the same prolific source. And, as they take more definit form and somewhat disengage themselves from the mass o custom, the institutions do not lose, but carry with them, tha approval and that conviction as to their indispensability fo welfare that were accorded to the mores. Anything that is i our mores is right, and so our institutions are the best. "Th res," says Sumner, again, "can make anything right and vent condemnation of anything." They are the approved ys of meeting the conditions of living, and are developed, epted, and practiced without much intervention of reasoned rpose.

They are to a society what, for example, density and color fur are to arctic animals; namely, automatic adaptations to vironment. Life-conditions are present and society has to e under them. This is rendered possible, or easy, or easier, adjustments in the manner of life or ways of living. Thus have a societal code characteristic, for instance, of the ctics or of the tropics, of isolation or accessibility, of over-pulation or under-population, of the country or of the city, peace or of war.

With this understanding as to the nature of custom, the west terms of all of society's institutions, and knowing that stoms and institutions are adaptive to life-conditions, we are w to inquire whether there are, acting upon the mores, rces which are the counterparts of those productive of adap-ion in the organic range. Are variation, selection, and redity, or factors which are their counterparts in the form evolution typical of human society, present and active in field? If so, what is their mode of operation?

The factor that leads off in any evolutionary process is varia-n. Without it all would be uniformity, equality, and change-sness. The existence of variation in custom and in custom-rn institutions is evident to anyone; demonstration of its esence would consist in an endless rehearsal of obvious tail.

Variation in the mores represents a series of tentatives, de-rting more or less from the accepted code, that are struck t upon by individuals in the pursuit of their interests. The dividual's function is that of an agency for variation. These ght departures from the code are in evidence all the time; in fact, the society's code is a sort of average or mean or type, about which cluster the codes of classes, sects, and other larger and smaller sub-groups. The individual may adhere to a number of these sub-groups, as his interests dictate. He may belong, for instance, to the miners' union, the Baptist church, the Socialist party, the Masonic lodge, at one and the same time. When interests change, other and new codes may appear, some of them departing widely in character, perhaps, from the general or typical code of the society at large. In general, the rise of such variations is a consequence of discomfort under the prevailing code; interests strain toward a better realization by way of change, small or great.

It is to be noted that variations upon customs and institutions may exhibit a high degree of rationality. They may represent true experimentation, because they may be set forth consciously and deliberately, after intensive study of situations and of societal laws, with the intention of securing more expedient adjustment of society to its life-conditions. But they come to nothing—they do not get into the mores—unless there is general concurrence in them. They remain stillborn unless verification is immediate, concrete, and positive. Rational variations—new details in the program of adjustment—are presented in every age. Whether they are adopted or not is another matter, for, as we shall see, there is not much of the rational in the selective process, except as the latter is seen, in retrospect, to have worked out expedient adjustments through the action of human agencies inspired by the most diverse and often irrelevant motives. If deliberate and planful action enters anywhere into the process of societal evolution, it is in connection with variation; for variation is, as we have seen, very much in the competence of individuals, and it is the individual, not the crowd, that will occasionally be found to think in terms of society.

Among these variations, whatever their provenance, selec on takes place. Such variations may be short-lived and exibited by only a few, or there may be a concurrence of many hich carries them forward until, perhaps, the code of the ociety at large has been profoundly modified. Some of the ariations live and some die out. Here is the fact of selection. ll through history, codes and institutions have appeared, ave persisted for a time, and have been altered or have assed completely away. But the process of societal selection somewhat involved. I should prefer, for the moment, erely to record its presence.

The remaining factor is heredity. It is clear enough to nyone that the mores are not inherited but learned—acquired new by each generation. Language is the best example: men ave used it time out of mind, but no one is ever born with command of it. Mores are also passed over from one group f adults to another. Hence heredity is not present in the ocietal range. But there is something there which discharges ssentially the same function and is a genuine counterpart. Vithout variation, we have seen, all would be monotony and hangelessness; but without heredity or some factor similarly onservative, all would be chaos and discontinuity. Even ocial life is not altogether that; and it is not that because in it oo there operates a conservative factor.

Transmission of the mores is by tradition. What matter f its channels are through the eye and ear, and not by way f the germ-plasm? Tradition, like heredity, tends to repeat he type. It is brought about through imitation, either sponaneous or induced. Spontaneous imitation is a natural acivity, common to animals and man, and especially marked, mong human beings, in the young. The receiver of the mores, hus transmitted, wants to receive, and takes the initiative in he transfer, as when the small boy apes his father. But such cquisition is also capable of being induced, where there is no ikelihood that it will be spontaneous, by precept and discipline. This is education, in its broadest sense. The receiver may be indifferent or even unwilling to receive, and the giver commonly takes the initiative, as, for example, in the "uplifting" of a "lower" race. Also, while spontaneous imitation carries all the mores indiscriminately, education carries a more or less wisely selected body of mores. It is clear that the former is the more natural, elemental, impersonal, spontaneous, and automatic process; the latter is effective as it succeeds in reproducing the essentials, at least in semblance, of the former, but in comparison it appears artificial. It involves, it has been noted, an antecedent choice or selection from the main body of the mores: we will teach the young certain things, and others we will try to keep from them as long as possible. This choice is supposed to be a reasoned and purposeful one; but such a selection has little of the sureness and severe correctness of an automatic selection.

These evolutionary factors are operative in the life of every society, from the family group to the nation. And they do not stop there. They are effective, on the grand scale, in the life of human society as a whole. There is a world-code that has been in process of formation with the establishment of proximity between the nations; for that proximity, brought about by the annihilation of distance, has meant altered conditions of life for many societies; and variations that have been demonstrated, under selection, to be expedient, have been transmitted until enough mores have come to be held in common by all, or nearly all, to justify the term "international code" or "world-code." Variations around this code, or in departure from it, may now be originated by a whole nation, and submitted for world-wide acceptance or rejection. Slavery, for example, has been rejected, while democracy has widened its range. And of late has stood forth Germany, as champion of a code that is still undergoing the ordeal of selection. These national variations on the world-code cannot be tested up as soon as, or shortly after, they appear—as Mormonism was tested up on the American national code—and the process of selection is the more imposing when it comes. We turn now to a survey of the essentials of the selective process.

It is about the factor of selection and its operation that the students and experts, genuine or alleged, in the social sciences, are at considerable variance. Few would dispute the operation of variation and transmission; hence I have reserved the contentious topic of selection for special consideration. And first let us be clear as to what "selection" means. The ordinary use of the word conveys the idea of picking out something desirable or good from a collection of things not so good or not so desirable. Such a conception of selection is a positive one. But that conception ought not to be carried over to color either natural selection or societal selection. The truth of it is that it is the unfit animals and plants which are selected—for death—and it is incidental to that process that we have a "survival of the fittest." It is the inexpedient custom that is selected—for disappearance—and it is incidental to that eventuality that the more expedient custom or institution survives. The useful conception of selection is therefore a negative one. If one does not get this firmly into his head, he is likely to be looking, in the primitive way, for some benign or malign agency where only impersonal natural or societal law prevails.

To attain to selection there is need of struggle and competition. It is not by discussion nor by guesswork nor by soulful yearning that the relative speed of several runners is settled; it is by a race. In nature there is the struggle for existence, and plant or animal forms succumb under it. Well, the life of societies also has been characterized by perennial struggle. It is sometimes to the death, and under such circumstances the selection is sharp and decisive, as it is in nature. Again, however, failure in the societal struggle is not visited by such dire penalties. Competition between societies runs all the way from wars of annihilation to rivalries in things of the spirit. The degrees of intensity of selection among the mores correspond to the degrees of violence and decisiveness in this competition.

The ultimate form of societal selection—one from which there is no appeal—is the war of annihilation. It was the tribunal before which all the earliest and most important collisions in societal policy were settled. War is still the court of last appeal when all milder forms of settlement have, as in the year 1914, failed. It is not supposed to involve annihilation nowadays, though, as the popular fancy noted, the treatment accorded Belgium and northern France savored of Attila the Hun.

Of course the mores do not fight each other, though we say, figuratively, that Protestantism fought Catholicism, or that there is a warfare between religion and science. It is not the codes of mores that fight; it is the men practicing the codes who do that. But the codes rise and fall with the successes of their sponsors in the competition. If a tribe that practices cannibalism comes into collision with another which abhors the custom, and is overcome, there is not likely to be much anthropophagy in that region for some time. For even if the conquered cannibals are not massacred, but enslaved, they lose, along with their power, their self-determination in the matter of their code. I think it will be clear, upon reflection, that great wars generally issue in so-called "new eras," "new worlds," or "new dispensations," which mean new codes of adjustment.

In the course of time the minor collisions of codes have come to be settled without much or any bloodshed. Enlightened states refuse to concern themselves much about the religious beliefs of their constituent groups, where once execution and persecution were rife. Revolutions have been tamed down into elections. Commercial and industrial warfare is carried on at the polls. Ballots replace bullets. But selection goes on just the same, so long as there is a competition, with winners and losers. Bagehot[7] has an important chapter on the "Age of Discussion," from which it appears that the voice and the pen have somewhat ousted the sword in the settlement of codes and policies.

This is not the place to go fully into the various forms taken by societal selection. It is plain enough, however, that there are plenty of them. It is only because they are so much a matter of course, being registered daily in the press for anyone whose attention has been called to their bearing upon societal evolution, that it sometimes comes as a shock, especially since we are nourished so largely upon romance and phantasms, to see that competition is always the indispensable precondition to development. If we think we have got on since primitive times, we may set it down to the diversities produced by variation and shown up in the incessant conflicts between men adhering to their differing codes. There is no fault to be found with the effort to minimize the tragedies of competition by setting up rules of the game; but those who dream of universal equalization, communalization, and pacification are proposing to abandon the agencies which have brought us from savagery to the civilization which we now acclaim.

The recurrent dispute about societal selection is as to whether or not men deliberately plan out and realize society's destiny. The plants and animals are supposed by most people to be under the sway of a vast force which they can in no way control; natural selection is thought to operate over them and to determine their destiny, as it were, from without. So far as they are concerned, they seem to be totally unconscious of what is going on, and have no say about their own destiny. But men do not like to believe that about themselves, nor about the nation to which they belong, nor even about the human race. They like to think that a people chooses its paths and policies, and consciously and purposefully advances toward some selected end. They make much of what might be called a rational selection by a people between codes and policies presented to them for adjudication. The country is figured as thinking things out for the country's welfare, as sifting evidence and being intellectually persuaded as to this and that. It seems to be assumed that "the people" can think in terms of a nation and will form a public opinion that operates as intelligent self-direction.

---

[7] Bagehot, W., "Physics and politics," 1902, ch. V.

Most of this sort of contention is myth-making, like the philosopher's picture of the "noble savage"—he never having seen one. Perhaps some rare statesman may rise to the power of thinking in terms of high generality; but it is at his peril, at least during his lifetime, that he tries to realize those thoughts. Lofty talk is appreciated, but action on the basis of wide generalization is repellent, as "unpractical" or "idealistic." Long after his death, such a statesman may get a statue; but that will be in consequence of the verdict of history, arrived at when the heat and passion have died down.

What moves men—the masses of men, whose numbers, social bulk, and formidable inertia are commonly left out of adequate account by theorists—is not thought, but emotion. And what sets emotion going is interest. And the circle of interest is, for most men, very narrow and very closely drawn around one's self. What sets the revolutions in motion, with the result of drastic selection in the codes, is not the cerebration of anyone over great issues, but the unendurable discomfort and awakened emotions of the masses. Their interests have been so outraged that anything seems likely to be better than the present. Hence a passion to overturn things and take a new start. It is the opportunity of the agitator, for misery is indefinitely credulous—hopelessly thoughtless—never intellectual and analytical. The "quadrennial revolution" or "biennial revolution," as an American election has been called, is a conflict of interests rather than one of state-craft: debtors *versus* creditors, ins *versus* outs. How can the masses pass intelligently on an issue like that of the tariff or the gold standard, when it takes a super-expert to understand them? Add to this the thick-and-thin adherence to party, the shufflings and compromises of leaders, the personal animosities, the campaign of emotional propaganda, and what becomes of the election as an agency of rational selection between proposed adjustments to the nation's life-conditions?

The fact is that there are a number of phases of any nation's code which are beyond the pale even of criticism; reason is not invited to scrutinize them, and if it attempts to do so, it is roughly bidden to desist. There are plenty of details in any code of mores which we cling to with as deep emotion as the savage shows for his medicine-bag, and which it would be sacrilege to submit to the searchings of reason. One cannot expect rational selection in the field of religion, nor of marriage and the family. The Mohammedan is not ready to analyze the merits and demerits of Islam, and abide by the results; nor the monogamist to make a cold-blooded study of the merits and demerits of pair-marriage. The people love one public figure, and overlook or smile at his defects; they hate another, and jeer at or misrepresent his virtues. Where feeling is strong, reason counts for little. It is cynically said that the chief function of the human mind is to think up reasons for doing what one wants to do, or to find good reasons for having done what one wanted to do.

These considerations may seem dismal to one who would like to believe that men think out society's destiny; but they do not seem discouraging to one who believes that the operation of the big, impersonal, automatically working forces always gets truer results than do the feeble powers of the human mind; that natural law is far more reliable than men's enactments. Most men would make hopeless errors in the piloting of society. But they are generally pretty clear as to their immediate personal interests. If these interests are in the hands of the interested—if people are minding their own business—they are in the custody of precisely those who are best capable of handling them. People with common interests make common cause and form competing groups; and out of the competition of such groups selection affecting the destiny of the whole society is bound to come.

It is bound also, in the long run, to result in adjustment. It is by such automatic, unplanned selection that all that we call improvement in adjustment has come to pass. The big man is the individual who correctly diagnoses the trend of events and rides in upon a wave of public opinion formed under a variety of motives which are often totally irrelevant to the results attained. That a wave of public opinion shall be raised, it is necessary that there shall exist a popular discontent, or irritability that can be excited to express itself in action, and, given this condition, it is necessary to fit the appeal to the variety of interests involved—interests which will be found to be for the most part personal, local, and but slightly or not at all relevant to any central principles. Masses of men do not look critically into the rational merits of a case. In this country, for instance, it is generally assumed that discomfort is due to governmental inefficiency or worse, and therefore hard times are likely to result in the upset of an administration. The process by *ex parte* conviction and snap-judgment is natural enough, and is shocking to those only who revolt at seeing things as they are.

It will be a long time before public opinion will form itself deliberately upon thought in terms of society. Few can envisage so large and complex a thing. The eugenists seem to hope that people will come to mate or refrain from mating with the interests of future generations in mind; but only the very enlightened few can be imagined as so doing. Human beings act upon interest as they see it; and interests are bound, for the masses of mankind (who must do the selecting that is done), to be narrowly circumscribed.

That this is a counsel of despair is nothing against it, if it is true. But it is not such a counsel. Societal evolution is a vast process, where the forces are massive and act with unhurried deliberation, endlessly interlocking, within a spacious field. There are dim ages of the process behind us, and ages untold yet to come. Selection occurs at every stage, and is but an episode along the course.

How then can men do anything, if all is determined by such cosmic power? Why struggle? Well, man can do something with gravitation, with the expansive power of steam, with the germ-plasm stream, although he can control the processes themselves in no degree. He can move things about, into the path or out of the path of natural forces. He can fix the mill-wheel beneath the falling water. He can place the cylinder in the way of the steam. He can isolate or bring together the sexes of animals. This has been done so successfully for man's interests and welfare that man has conceived the idea that he is master of nature. But what he has done is to learn nature's ways and adapt his action to them. At a pinch he is nature's plaything and victim: the earth shakes a little, and his great works collapse; the volcano spills a little gas over its crater-rim upon a town, and the lords of nature lay them down and are still.

It is not otherwise with the elemental forces of the societal realm. They cannot be mastered; they must be studied and known and adjusted to, as a condition of societal well-being. The efforts of many a would-be benefactor and uplifter of the race are sterile or even harmful because he is trying to do what he would realize, if he knew what a society is, and what can and cannot be done with it, to be out of the question.

Every one knows that water will not run uphill; yet in the societal realm there have been plenty of well-meaning people, through the ages, who have worn out and wasted their lives in unhappiness, trying ineffectually to overcome a societal tendency and law which are equally inevitable. If an ignoramus plays about in a chemical laboratory, we keep our distance, for we expect trouble as a result of ignorance of chemical substances and laws. Knowledge of the experimenter's good intentions or orthodoxy does not reassure us at all. But we easily permit the uninformed meddler to prowl about the structure of society, poking and tinkering, apparently in the belief that, provided his intentions are good, nothing but human weal can result. We are bound to learn, sometime, that powerful forces are at work within the societal range, and that ignorant tampering is even more dangerous here than elsewhere because so many more people have to endure the consequences. Then we shall want more knowledge of these forces, that we may adjust to them.

Intelligent adjustment to the known inevitable is as rare on earth as automatic adjustment to the unknown inevitable is common. But the former is an abridged and less painful process. Adaptation is sure, because it is the condition of comfort and of life itself. Adaptability is that which hurries and eases the process. Of all earthly things that which possesses the supreme capacity for swift adaptation is the human mind. But that capacity is undeveloped, fettered in its action by pseudo-knowledge, bias, caprice, and sentimentality—except where tests and verification are immediate and conclusive, and where, therefore, knowledge is almost automatically acquired. Nowhere is real knowledge and science so little in intelligent demand as in the societal realm, for the latter is self-sown to whims and dreams of all varieties. It is thought that man can here have his own will; here, at last and at least, he is lord. He senses no elemental powers in the field. Here, of all places, he needs but to plan and "create"; pass resolutions and regulations; think out utopias in bed and then rise and gird himself to their realization; abolish property, or the family, or government, or religion. Naturally he is taken by the theory that societal evolution is by individual purposeful action. Naturally he regards insistence upon the control exerted by spontaneous, automatic, and impersonal forces as an assault upon his "free will."

Sometimes, in a crisis, the verities stand forth and enforce to themselves an attention which they do not get in ordinary times. Many people have been for some time perplexed and in weak despair because their comfortable little formulas have cracked and broken under the weight of explanation laid upon them. Perhaps it is a favorable occasion to offer the contention that "social theory" is not wholly academic after all.

CHAPTER XI

CLIMATE AND THE EVOLUTION OF CIVILIZATION

ELLSWORTH HUNTINGTON
RESEARCH ASSOCIATE IN GEOGRAPHY, YALE UNIVERSITY

Factors in Human Progress

Human progress depends upon three great factors. The first is inherent mental capacity including both intellect and temperament, the second is material resources, and the third human energy. If any of these is lacking, civilization stagnates or even retrogrades. Where all are present civilization moves onward. How far do these three depend upon physical environment? How far does man's higher evolution agree with the evolution of plants and animals? At first sight it appears as if there were a great gap between the evolution of man's body and of the mind which we are now considering. In one sense there is undoubtedly such a gap. Yet the more we study the matter, the more we see that from the lowest protozoan to the highest philosopher a marvelous unity pervades all nature.

All progress in civilization, whether material or moral, arises from ideas in the minds of individuals. Therefore the first requisite of any advance is men with unusually gifted minds. Some races seem to be capable of producing such men in far greater numbers than do others. We rightly think of ancient Greece as preëminent in this respect. Galton, the founder of modern eugenics, has said that the average Athenian in the age of Pericles was as much superior to the average Englishman of today as the Englishman is superior to the African. Although a few students still claim that all races possess equal innate capacity and might rise to the same level if given equal opportunities, their conclusions lack statistical foundation. Judged by their achievements and by all the exact tests yet available, the brains of races differ as do those of individuals, although not to so great an extent.

What causes these racial differences? We cannot answer until the biologists give us more light on the origin of the new forms called mutants (see Chap. XIII). If it be asked, however, what segregates and preserves certain mutations or minor variations of the brain and eliminates others, thus giving rise to new racial qualities, we can answer with considerable certainty. Environment by means of natural or social selection allows some types to perpetuate themselves indefinitely, while it rigidly exterminates others. The environment may be either physical or social. Which is more important no one knows. Here we are not concerned with social environment except as it varies from place to place in response to physical or geographic environment. Among the various physical factors, climate is apparently the most important. As Professor Lull has said on an earlier page (page 110); "Changing environmental conditions stimulate the sluggish evolutionary stream to quickened movement. Whenever it has been possible to connect cause and effect, the immediate influence is found to be generally one of climate." Nevertheless the form of the land, the character of the soil, the nature of the minerals, and the location of human activities in relation to land and sea are other geographic factors which play an important rôle. Moreover, all the environmental factors, both physical and social, may act indirectly through such processes as migration and disease.

Inherent Mental Capacity. In considering the way in which man's inherent mentality is influenced by physical environment we must either deal with recent occurrences whose final effect upon racial character cannot yet be known or with events which occurred long ago and as to which our knowledge is largely based on inference. This is unsatisfactory and leaves many questions still unsolved. Nevertheless it helps toward the discovery of the truth. One among hundreds of examples of each kind will show the general line of reasoning pursued by the new ecological school of biologists, geographers, and others.

The Black Belt of Alabama provides a modern illustration of the processes by which geographical conditions sort out special types of people to become the inhabitants of a clearly defined geographical region. This belt of black and very fertile soil lies in the south central part of Alabama. It is almost level, and is far better for corn, cotton and other crops than are the sandier, poorer soils in other parts of the state. The summers are long and hot, and very good for cotton; the winters are not harsh enough to demand great effort in order to withstand them. In this favored region one sees today a curious set of anomalies. In the rural districts less than one-fifth of the people are white and more than four-fifths are colored. The white farmers are richer than in any other part of Alabama and their holdings of land are larger. The colored farmers are poorer than anywhere else and their holdings are very small. Practically all of the white farmers own their land; the colored farmers are almost universally tenants, more so than in almost any other part of the United States. The white people are better educated than other similar rural groups in that part of the country and send an unusual percentage of their children to college; the colored people are exceptionally illiterate and their rate of progress in education is uncommonly slow. The white people produce an unusually high percentage of able leaders; the colored people are peculiarly leaderless. Strangest of all, perhaps, the yield of cotton per acre on this superlatively good land is less than in any other part of Alabama.

The explanation of these and other anomalies appears to lie in the fact that the soil and climate of the Black Belt have caused the segregation of an unusually competent group of white farmers and an unusually incompetent group of colored farmers. If these two groups were to be isolated for several generations, and if the processes which have segregated them from the rest of their kind should continue to act, it appears probable that two stocks of people would become well-established biologically, and that their innate temperamental and intellectual traits would differ not only from one another but from those of other stocks of their respective races.

The method by which this incipient differentiation of racial stocks has been effected is clear. When Alabama was settled by white people the intelligent thoughtful far-sighted type of migrant was more likely to learn about the good soil and great possibilities of the Black Belt than was the more ignorant and happy-go-lucky type. When land had to be purchased the more competent settlers were the ones who could afford to buy the better land. When difficulties beset the pioneers, the shiftless and incompetent people who happened to have procured good land were usually the ones whose mortgages, for example, were most likely to be foreclosed. They wandered away to cheaper land, and their place was taken by people who displayed greater ability. The census figures for almost any part of the United States show that this same sort of selection is still occurring. Under ordinary circumstances the foreign-born farmers in counties where the land is good are more literate and apparently more able than are those on the poorer land in the same states. The children of each type are likely to marry their own kind. Thus on a small scale there occurs a kind of cerebral segregation which tends to separate people according to the physical quality of their brains so that those on one kind of soil differ in both intellect and temperament from those on another kind of soil.

Among the negroes of the Black Belt the case is even clearer than among the whites. Because the climate as well as the soil of that belt is admirable for corn and cotton, negro slaves were in great demand from an early period. Because the white men were intelligent and prosperous, they could buy large numbers of slaves. The presence of numerous negroes drove away almost all white men of the classes whose labor competed with that of the slaves, thus increasing the tendency toward the segregation of a rather high type of white man in the Black Belt. At the same time the plentiful crops of cotton caused an opposite type of segregation among the negroes. The planters wanted only a few high-grade slaves as house servants; but they wanted great numbers of cheap husky slaves who had brains which gave rise to little skill beyond that needed to pick cotton. That stupid kind of slave was cheap, and was the sort that the planters of Kentucky, Tennessee, and Virginia, where there was little cotton, were glad to sell and get rid of.

After the Civil War the negroes of greater initiative and higher mentality wanted to get farms of their own. They could not buy land in the Black Belt, and they had little chance there anyhow. Many of them moved away to poorer soil where the opportunities were greater. During the World War a similar draining away of the abler, more progressive negroes occurred by reason of the demand for labor in the cities and in the North. Thus for many generations the fertile soil and moist warm climate have provided conditions which have attracted or retained the dull easy-going stupid type of negro but repelled or sent away the better type. The inevitable result is dire poverty, extreme illiteracy, poor farming, a small yield of cotton per acre, and the segregation of a type of negro with low innate ability. Soil, climate, and social conditions have all coöperated in this result, but its localization in one special spot is due primarily to the soil and climate. If all the world were geographically uniform it might never have occurred.

Turn now to a second and more ancient example of mental and social evolution. No matter whether we believe in the Nordic "myth" or not, there can be little doubt that the brains of the people of northwestern Europe are so constituted that those people possess an innate tendency toward unusual activity, boldness, self-reliance, initiative and other allied traits. Whence comes this tendency? The geographer and ecological biologist reply that one of the factors is repeated and highly selective migrations under the stress of changes of climate. The corresponding ability of the non-Nordic people of the lands around the eastern Mediterranean in earlier times seems to have been due in part to this same cause. All migrations are more or less selective. The rigidity of selection increases in proportion to the difficulty of the migration. If part of the population migrate and part remain in the old home, there is bound to be some difference between the two groups. If the migrants are assisted and even urged to go to a new land they may be less competent than those who stay behind. If on the other hand they go of their own volition in the face of dangers and difficulties they are almost certain to possess more than the average degree of initiative, optimism, versatility, resourcefulness, and persistence. Moreover, if the difficulties of the new home are great, many of the weaker, less competent, less optimistic, and less versatile migrants are eliminated. Some go back to the old home; others die. The death rate is especially high among women and children. At Plymouth half the passengers of the Mayflower died in the first year; at Jamestown four-fifths perished or returned home in the first few years.

If the whole population of a given area is obliged to migrate, the selective process may work even more strongly. The reason for this is that in a partial migration a residue of highly successful people often stays in the old home along with the conservatives because its members are well satisfied and do not want to make a change. They leaven the lump so that the contrast between migrants and stay-at-homes is reduced. But if a migration of practically the entire population requires a long period without settled homes and is accompanied by much hardship, these successful people together with the ones of the highly pioneer type are likely to survive while others perish. The weaklings, physically, intellectually, and temperamentally tend to be weeded out. Some try to return to the old home; some stop before the desired goal is reached; and many die. If the migration takes people into a new social environment the elimination of the weaklings is increased by human hostility. Even in modern days the man of strange customs finds scant welcome in a new land, and often has hard work to support his children. In a new physical as well as social environment the qualities of versatility, inventiveness, adaptability and the like are especially likely to cause their possessors to survive. It makes little difference whether immigrations take place en masse or in the commoner form of a slow drifting of population. In either case they are more or less selective; the more prolonged and difficult they are, the more rigid the selection; and in practically all cases the selective process acts more powerfully upon women and children than upon men.

Where certain clearly defined types of mentally alert and physically strong people have thus been sorted out for preservation at the end of a long hard migration still another factor tends to preserve their special characteristics as a permanent racial asset. That factor is marriage. In the old home the young people might have married persons of almost any intellectual and temperamental type. In the new home they can marry only those belonging more or less to their own type, for the other types have been eliminated. Of course the succeeding generations show a tendency back toward the average type of the original community, for that is the universal biological law. But after a drastic selective process the future biological inheritance is probably never quite the same as in the past. How true this is may be judged from the inventiveness of the Eskimos, the canny intellectual quality of the Icelanders, the tendency of persons of Puritan descent to become leaders in the United States, the persistent leadership of the Brahmans, and the peculiarly high social, economic, and moral level of the Parsis of India. All these groups are the end products of drastic selective processes arising through migration, and all are still notable for characteristics which appear to have been thus segregated.

Among the factors which cause migration few are more potent than climatic variations. Even in our own day there is remarkably close connection between the weather, the crops, and the volume of migration. Australia actually lost population during one especially dry period. Emigration from Ireland and even Germany has fluctuated in close relation to the amount of rain and the consequent size of the crops, especially the potato crop. In the past the connection between climate and migration appears to have been even closer, just as it is now among more primitive people.

At the height of the last glacial epoch northwestern Europe together with great tracts surrounding the Alps and other mountains was shrouded in ice. Vast regions on the outskirts of the ice sheets must have been so cold and stormy as to be practically uninhabitable. But these tracts had previously been populated. That earlier population must either have migrated or been exterminated. Judging by what happens in our own day we may safely assume that both things occurred. Part of the population migrated, and part died out more or less gradually. If what we have just said as to the selective power of migration is true, the migrants who finally survived when Europe suffered glaciation must have been unusually competent both physically and mentally. They must have gone southward or southeastward into the lands bordering the Mediterranean; there was nowhere else to go. The presence of such selected migrants and their descendants goes far toward explaining the great outburst of human ability which gave rise to the earliest civilizations.

Another phase of the matter is no less important. When northwestern Europe was shrouded with ice, and central Europe and northern Asia were too cold and stormy for habitation, the deserts of North Africa, Arabia and Central Asia were far more habitable than now. From all of them come reports of abundant traces of early man in districts now so dry that no one lives there. As the glacial period waned, the deserts became drier and less habitable. Hence the people had to move out or perish just as in the colder regions during the opposite phase of climatic change. They doubtless behaved as did the inhabitants of the regions that had previously become too cold for habitation. A very high and selective death rate presumably weeded out the weaklings, while migration and its hardships and struggles presumably still further eliminated those who fell below a certain level. The goal of migration from the desert must in many cases have been those same lands of Egypt, Mesopotamia and their neighbors to which people had previously been driven by the onset of a glacial climate. Other migrations must have carried the selected remnants of desert peoples into China and North India, and thus into all of the chief regions where civilization first developed.

The glacial period was highly complex. It included at least four main epochs when ice shrouded northern Europe; between each pair of glacial epochs there appears to have been an interglacial epoch with a climate at least as mild as that of today. Moreover, since the last glacial epoch there have been several glacial stages, substages and smaller climatic pulsations, the last of which belong to the historic period (see Chap. IV). Each of these has done its part in sending selected migrants first out of the cold stormy regions and then out of the dry regions. The chief zone where these two streams have met has been the lands of the eastern Mediterranean. There then, we should expect to find an intricate mixture of races compounded of especially virile, competent, adaptable, and progressive elements of the European population on the one hand and the desert population on the other. Such a mixture ought to produce a high percentage of persons of unusual ability. That is just what it has done, for the people who there made the greatest early inventions and discoveries in mathematics, writing, astronomy, agriculture, metallurgy, religion, government, art, and many other lines were geniuses of a high order.

But how about Europe? Why has it superseded the Orient? Many factors, economic, political, religious, climatic and the like have doubtless played a part, but here let us concentrate on racial inheritance and its relation to climate. Northwestern Europe is the newest part of the Old World. It is new because 30,000 years or so ago it was shrouded in ice. Even as late as 850 to 350 B.C. central Europe suffered a recurrence of cold and stormy conditions which caused the abandonment of all the settlements in the lowlands of Switzerland except in the warmest valleys. In *Climate Through the Ages,* C. E. P. Brooks quotes Gams and Nordhagen as saying that this prolonged "climatic fluctuation had the appearance of a catastrophe." Because of the relatively recent occurrence of such unfavorable climatic conditions, as well as for other reasons which we shall soon mention, central and western or northwestern Europe were reserved, so to speak, almost to our own era. They today form one of the most habitable parts of the world, yet only 2,500 years ago they were almost useless for people in the stage of culture then prevailing. For this reason, Germany, France, Britain, Scandinavia, and the neighboring small countries have been the goal of some of the most recent great migrations. History is full of the dim story of such movements. We see Celts, Cimbri, Teutons, Angles, Saxons, Franks, Goths, Vandals, Norsemen, Huns, and many other groups surging back and forth, but, in general, moving into lands that once were in the grip of a glacial climate but now are very habitable.

The migrations of these people subjected them to all sorts of hardships. Of that we are certain. We infer that the migration also exerted a strong selective effect, especially upon the women and children so that only the most vigorous in mind and body were preserved. If that is so, we conclude that the present racial qualities of northwestern and central Europe arise partly from the fact that the inhabitants are descendants of ancestors whose physical and mental competence acted as a selective factor to insure their preservation during prolonged migrations. And those migrations apparently arose under the impetus of the latest phases of the climatic changes of recent geological times. By the same token the vigor of the United States, Canada, Australia, and New Zealand is partly due to the fact that their people represent still another slight but real racial change due to selective migration.

Material Resources. Material resources are no less important than innate capacity in their effect upon civilization. They are of course still more closely connected with physical environment. A Socrates dwelling among a people with no resources except the sands of Arabia might never have been heard of. Mohammed had to live in an oasis and not in the sand. His religion would scarcely have been able to dominate nearly a seventh of mankind if it had not speedily spread to places with abundant material resources. The Eskimos show the importance of material resources still more clearly. Though possessing the same power of passive endurance which is characteristic of the Indians, these people of the snow and ice seem to have also a strong strain of inventive ability. Their stone lamps, their drills for lighting a fire by twirling one stick upon another, their bird snares, their clever boats which make a man and his canoe parts of a single watertight structure, all show the earmarks of ingenious minds. Nevertheless, civilization has not made progress among the Eskimos. Even if they were not afflicted with the inertia of the North, the absence of material resources almost forbids a high civilization. Here, as in so many other cases, climate is the factor which mainly determines the resources. No crops will grow, and even the reindeer does not thrive in many parts of the Eskimo coasts. Hence hunting is the only possible mode of life. Hunters must be nomadic. They cannot accumulate any large amount of the material resources which are needed as aids to progress. If the white man with his claims to superiority were placed in the home of the Eskimos with no outside resources, would it be more than a few generations before his mode of life and manner of thought would be much like theirs? The retrogression of the white fishermen in northern Newfoundland and Labrador, where the conditions are much better than in the home of the Eskimos, is a pointed answer to this question.

The effect of climate upon material resources and of material resources upon civilization is well-illustrated by a comparison of the Indians of California and Utah with their Pueblo neighbors in New Mexico. The pre-Columbian inhabitants of California and Utah were abject savages. They dwelt in flimsy brush huts, and ate rabbits, lizards, grasshoppers, acorns, and other equally poor kinds of food. Because food was so scanty they lived in very small communities, and were forced frequently to move from place to place. Because of their wandering, isolated life they had only the rudiments of social and political organization. All in all, they were well-nigh the lowest of the American aborigines. The Pueblo Indians, on the other hand, had risen far beyond mere savagery and were well along in the stage of culture known as barbarism. They had an excellent diet of corn, beans, and squashes, with at least a fair amount of meat. Not being obliged to wander, they lived in compact, well-made adobe houses. Their villages were large enough and near enough to one another so that intercourse was frequent. Hence they had a highly organized social and governmental system. They had also developed a series of complex religious ceremonials that did much credit to their mental powers. Among the aboriginal people of America they stood not far from the top.

The contrast between these two neighboring types was apparently not due to racial differences. The Hopis, who were among the most advanced Pueblo people, were apparently of the same race as the Utes, who were among the lowest of the other type. Material resources seem to have been the main cause of the contrast. The Pueblos had behind them the resources of agriculture, while their savage neighbors could not raise crops. This difference was due to climate. At first sight the climates of the two regions appear closely similar. Both are dry. Salt Lake City, in the home of the Utes, for example, has an average rainfall of sixteen inches per year. Santa Fé, in the center of the Pueblo district, receives a yearly average of nearly fifteen inches. Why, then, was agriculture and hence civilization so different in the two types? The answer is found in the season of rainfall. At Santa Fé the months of June, July, and August have an average of 8.4 inches of rainfall, whereas at Salt Lake City the same months average only 2.2 inches. Los Angeles, where lived some of the lowest California Indians, has almost the same rainfall as Salt Lake City, and the summers are practically rainless.

Today the greatness of California depends upon its farms more than upon any other material feature; and the farms of Utah are by no means to be despised. But the staples of agriculture in these regions are wheat, barley, beets, vegetables, grapes, oranges, and other orchard fruits. These are raised largely by means of elaborate systems of irrigation which utilize the winter snows upon the mountains. Where irrigation is not practised, cattle are the great agricultural resource. Another foundation of prosperity is mining. All these things are essentially European. The crops which place parts of California and Utah among the world's garden plots are not indigenous to America. The cattle and horses which browse on a thousand brown hillsides had no counterpart in the New World before Columbus. Since iron tools were unknown, the art of mining was impossible. So far as anyone has yet pointed out, the poor Indians had no plants that would serve in place of those with which the early people of the Old World were blessed. The absence of summer rain, which is typical of subtropical climates, caused the vegetation to be scanty, and hence wild animals, wild seeds, and fruits were also scarce. Thus the people were condemned to be nomadic hunters and to remain in the lowest stage of civilization.

Turn now to the Pueblo region. A rainfall of six or eight inches in the three summer months seems insignificant. Yet it made all the difference between savagery and barbarism. In its absence the Utes and the California Indians were as much below the Hopis and the other Pueblo tribes as the Pueblos are below modern Europeans. The one great cereal of the New World is Indian corn. The two other staple crops that were widely raised in the dry regions of pre-Columbian America were beans and pumpkins. All of these can grow where there is moisture in summer, but not otherwise. To raise them by irrigation in places like Utah and California is practically impossible for primitive people. On all except the larger streams, whose control is beyond the power of beginners, the floods usually come to an end before the time when the crops most need them. Where the Pueblos live, however, the summer rains produce floods just when the corn, beans, and pumpkins are most eager for water. Hence these crops provided the early Americans with the basis for a well-developed system of agriculture, and progress was assured. Even if the Utes and the Indians of California had been more inventive than the Pueblo Indians and had produced men with minds of unusual brilliancy, the lack of material resources adapted to the early stages of development would probably have kept them permanently in savagery.

The material resources thus far mentioned depend upon climate. In this they are like nine-tenths of the world's resources. All kinds of food, all kinds of clothing, and a large part of the materials used for shelter depend absolutely upon climate. The fish of the sea, the fowl of the air, and the beasts of the field, even though they may prey upon other animals, are in the last analysis wholly dependent upon the vegetation which feeds either them or their prey. Vegetation is absolutely dependent upon temperature, rainfall, winds, ocean currents, and other climatic conditions. Soil, to be sure, is of much importance, but all soils would be moderately fertile if they had never been subjected to any except a favorable climate. There would be few great wastes of sand, salt, gravel, or naked rock, for these rarely arise except under aridity, glaciation, high wind, or other extremes.

In spite of the overwhelming preponderance of climate in determining the nature of material resources, certain articles, such as iron and coal, occur with little reference to heat or cold, moisture or drought. Their use, however, depends largely upon climatic conditions. Iron was well-known in Mediterranean lands at the time of their highest civilization. Nevertheless, its use was strictly limited by the scarcity of fuel in a subtropical climate. Only when iron was smelted in countries like England where the climate fostered dense forests did its use increase rapidly. When the value of coal was at last realized it added wonderfully to man's material resources. Yet even here the limitations of climate are strict. In Alaska today the presence of coal does little to advance civilization. It brings a group of coal miners whose chief desire is to make money enough to enable them to get home again. Because Alaska is so cold and inhospitable the regions with better climates farther south are the ones that profit by its coal. So, too, with the iron mines of Gellivara in northern Sweden. A few small towns have sprung up, but the places chiefly benefited are the cities of southern Sweden where the climate is less severe. Thus it appears that all kinds of resources are strictly limited by climate either in their occurrence or in their use.

Energy. The importance of energy in advancing civilization is not so well understood as is that of inherent mental capacity and material resources. Darwin says that the latent capacities with which most men are endowed are so great that inherent ability is less important than the zeal and determination, or in other words, the energy with which that ability is used. In our own experience have we not scores of times had good ideas—perhaps revolutionary ideas—with which we toyed for an hour or a day, only to forget them because we had not the energy to undertake the hard work necessary to bring them to fruition? Such energy is needed not only by the individuals of unusual capacity who make the great inventions, but also by the people around them who must put the new ideas into effect. "We have but partly solved the mysteries of the progress of civilization,—when we have pointed out that each tangible stage of progress owed its initiative to a new invention or discovery of science. To go to the root of the matter we must needs explain how it came about that a given generation of men was in a mental mood to receive the new invention or discovery."[1] The necessary mental mood is "alertness," which depends partly upon inherent mentality, partly upon training, and partly upon health and physical energy. In the march of civilization such health and energy appear to be quite as important as either inherent mental capacity or material resources. Physical energy is partly the result of proper food, clothing, and shelter, partly the result of inherited ability, and partly the result of freedom from specific disease. But a man may be well fed, well dressed, well housed, of good ancestry, and free from specific disease, and yet may not feel like work even when he has no special occasion to be tired. This is especially true in respect to the surplus energy which is so large a factor in causing men to do the extra, uncalled-for work which gives rise to most of the great forward steps of human progress. That extra energy over and above mere good health is largely a matter of climatic stimulus. Health may be possible in almost any climate; it is doubtful whether the fullest efficiency is possible except in an ideal climate.

Effect of Climate upon Man's Efficiency. This matter is so important that we shall dwell on it at some length. Whereever we find him, man seems to be characterized by a most delicate physiological adjustment to climate quite apart from the innumerable indirect effects through inheritance and material resources. In this he appears to be like all other organisms. For every species of living being there seems to be a certain optimum or most favorable condition. As the temperature, humidity, or other climatic elements depart more and more widely from the optimum, the animal's reproductive rate diminishes, its general strength declines, it becomes more susceptible to disease, and its life is shortened. Between the optimum conditions and those which cause death there may be a wide range in which life and even health are possible, but in which the organism is not at its best.

---

[1] Williams, H. S. Article on "Civilization" in the "Encyclopaedia Britannica."

One of the great lessons of biology is that man's physiological nature is essentially the same as that of the lower animals. A law which applies universally to them applies also to him. This is eminently true in respect to climate. By measuring the rate of reproduction of infusoria, the rate of growth of plants, the amount of oxygen consumed by crayfish, or the length of life of the boll weevil we can arrive at an exact estimate of the effect of climate upon these various organisms. In the same way we can measure man's response to climate and find out just what conditions are best and how much harm is done by departures from the ideal. Thus far man's physical relation to climate has been tested chiefly in the following ways: (1) by frequent measurements of the weight of healthy persons or of those suffering from tubercular or other diseases, (2) by daily or weekly tests of people's strength, (3) by examination of the amount of work done by specially chosen subjects or by piece workers in factories day after day throughout long periods, (4) by measuring the amount of carbon dioxide given off in the breath of people who are at rest or at work under various climatic conditions, (5) by measuring the bodily metabolism and the composition of the blood and secretions among people in different environments, (6) by tabulating people's estimates of their own feelings of comfort or discomfort at different temperatures and humidities, and (7) by ascertaining the amount of sickness and death at different seasons and under different conditions of weather. All of these methods yield substantially the same results. So far as temperature is concerned they indicate that people's health is best and their physical energy greatest when the average temperature for day and night together is from 60°

to 68° F., which means when the noon temperature ranges from about 65° to 75°.

Among the methods mentioned above, the study of deaths is at present more universally available than any other. Death is one of the few occurrences which takes place in all parts of the world and can easily be reduced to accurate statistics. Such statistics are kept by all of the more advanced governments. Thus an enormous body of valuable facts is easily available, and needs only to be tabulated in order to give significant results. In *World Power and Evolution* I have published the results of a detailed study of about 9,000,000 deaths in Italy, France, and the United States, and of a more cursory but no less exact study of a much larger number in Belgium, Germany, Sweden, Finland, and Japan. The most important result is a series of "climographs," samples of which are shown in Figures 69 to 73. These particular climographs show to what extent the deaths during months with any specified temperature and humidity fall short of or exceed the normal. Temperature is indicated at the left and humidity at the top. The heaviest shading (Figure 69) means that on an average the deaths during months having the conditions included within its area were at least 10 per cent less than the normal. The less heavily shaded area between the 10 per cent line and the zero line means that on an average the deaths in months having any of the combinations of temperature and humidity falling between these lines range from 10 per cent below the normal up to the normal. The next lighter strip indicates conditions under which deaths range from normal to 10 per cent *more* than the normal, and so on. The lighter the shading the greater the number of deaths, and the less the vitality and energy. The practical use of the diagrams may be illustrated by an example. We want to know what degree of health to expect during a month having an average temperature of 50° F. for night and day together

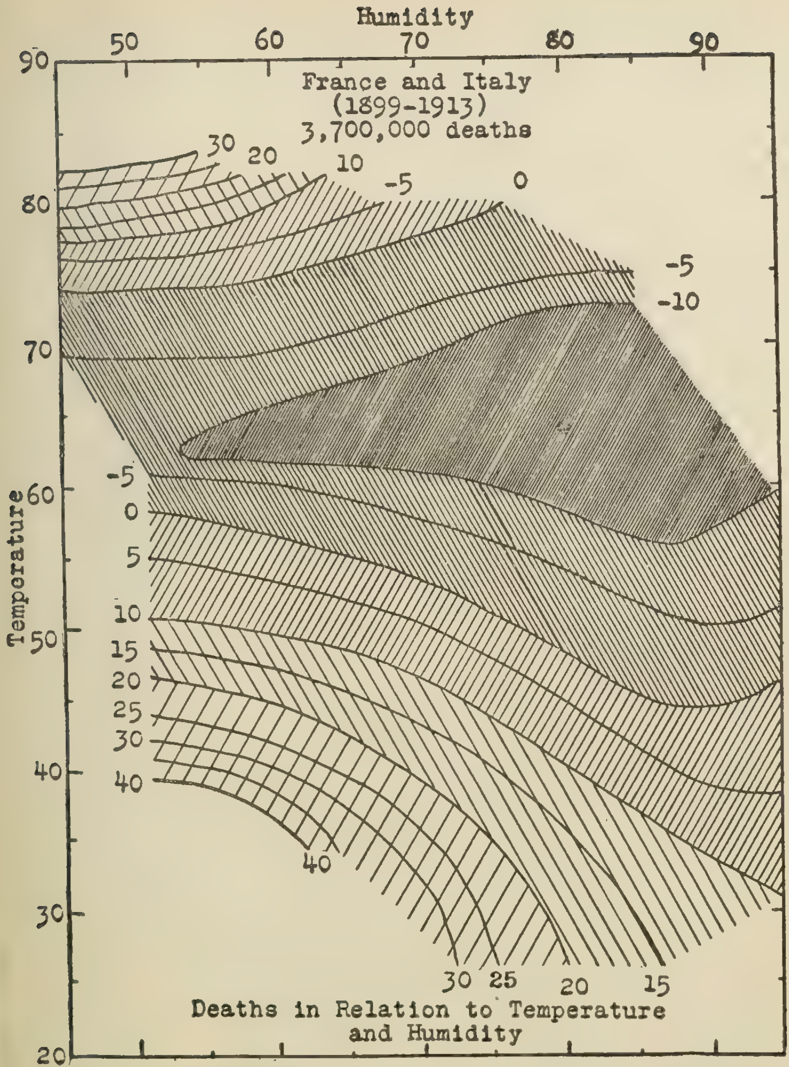


FIG. 69.—Climograph of France and Italy. Based on 3,700,000 deaths, 1899-1913.

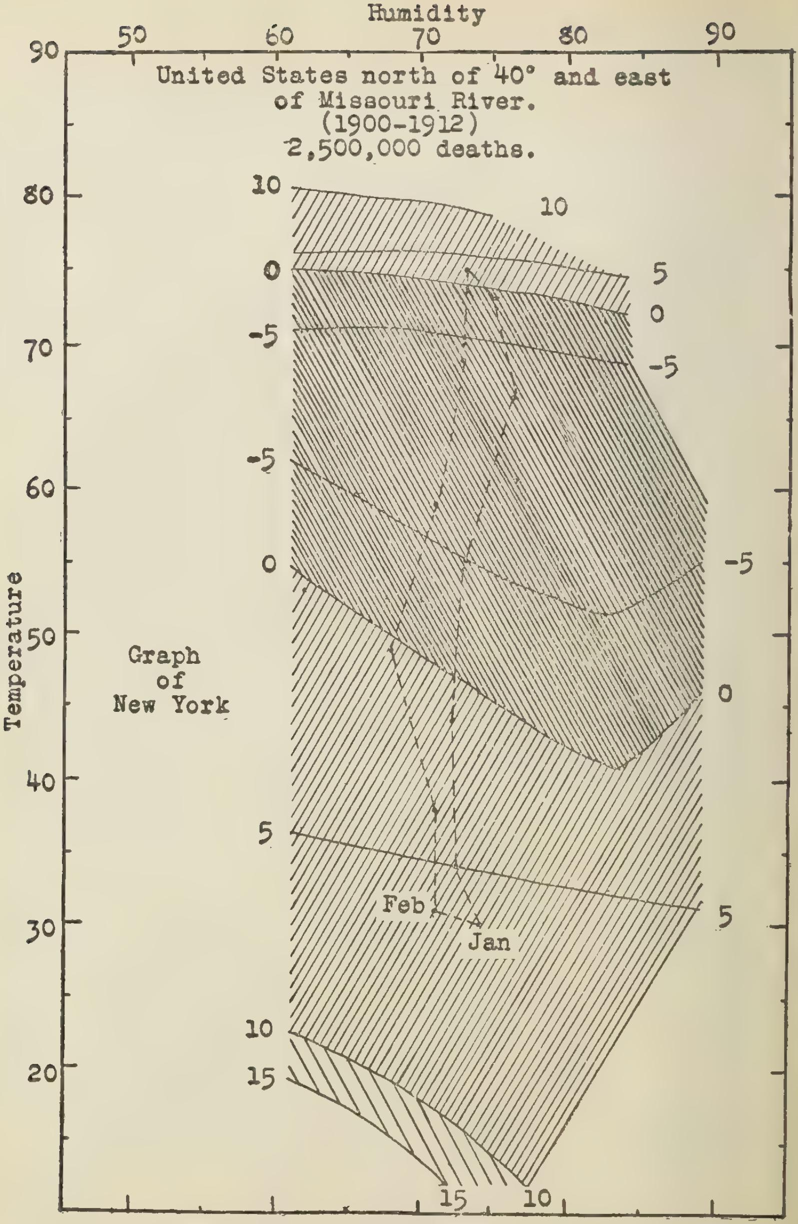


Fig. 70.—Climograph of the northeastern United States. Based on about 2,500,000 deaths in the United States north of 40° latitude and east of the Missouri River, 1900-1912.

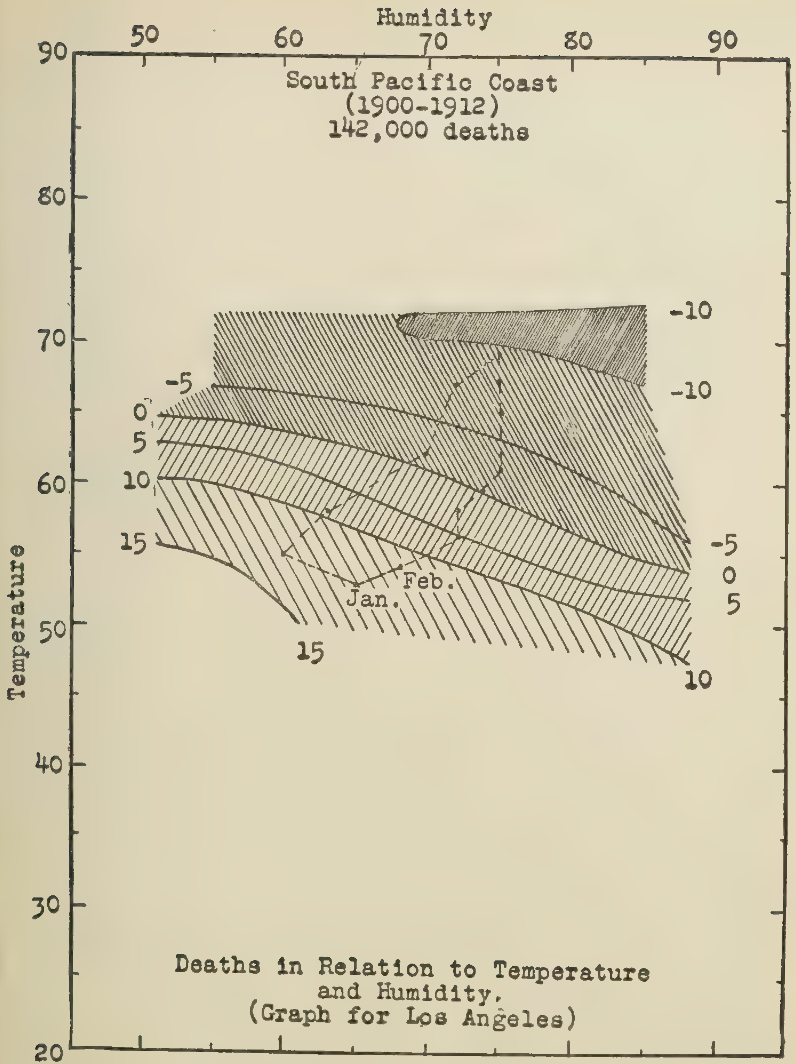


FIG. 71.—Climograph of Southern California. Based on 142,000 deaths at San Francisco, Sacramento, Los Angeles, and San Diego, 1900-1912.

and an average relative humidity of 70 per cent. In Figure 70 find 50° in the scale on the left. Follow this level to the right to a point in line with 70 per cent as marked at the top. This point lies a little above the zero line and about one-fifth of the way toward the minus 5 per cent line. Therefore we infer that on an average in the northeastern United States the months with a mean temperature of 50° and a relative humidity of 70 per cent have 1 per cent less than the normal number of deaths. Such a month in spring after a hard winter may have 10 per cent more than the normal deaths, while in the fall after a cool summer it may have 12 per cent less than the normal, but the average is 1 per cent below normal.

The method of preparing these diagrams is as follows. Certain cities were first selected to cover all parts of each region, namely fourteen in France, fourteen in Italy, twenty-two in the northeastern quarter of the United States, and four in California. For each place tables were prepared showing the mean temperature, mean relative humidity, and number of deaths for each month. Next the yearly deaths in the first and last halves of the period under discussion were averaged to see how rapidly the number was increasing or diminishing. On the basis of these figures, and assuming that the change in the number of deaths due to increasing population and to improved sanitation progresses uniformly, the normal for each month was obtained. Allowance was made for the varying number of days in different months. Then for each month the departure of the death-rate from the normal was calculated in percentages. These departures were next tabulated according to temperature and humidity. Contagious diseases were included and cause some irregularities which have been smoothed out in the diagrams here presented. It must be clearly understood, however, that the irregularities are slight, and their effect is merely to cause the lines separating the different zones to be wavy instead of smooth. As a matter of fact, contagious diseases are in general worst under the same climatic conditions which are worst for other diseases.

By the method described above, each place is compared only with itself. This avoids the serious difficulty which arises if actual death-rates are employed, and if all places are compared with the same standard. The death-rate of one town may be high because of poor sanitation, or because a great number of people work in factories. In another it may be low because a large number of young people have migrated thither or because the occupations are unusually healthful. Therefore comparisons of the death-rates of different places are misleading. According to the method here employed, however, it makes no difference what the actual death-rate is. We deal simply with the degree to which the deaths fall above or below the normal for the particular place and period in question.

It will readily be seen that diagrams 69 to 71 present the same general features. This would be much more evident if the range of temperature in California and of humidity in the eastern United States were not so small. Nevertheless, in each diagram the outstanding feature is a central heavily shaded area of few deaths and high physical energy. When the weather conditions are like those included within this area, the number of deaths averages much less than the normal. In Figures 69 to 71 and in others of similar character not here reproduced the favorable conditions when deaths are more than 5 per cent below normal range as follows:

Mean Temperature at Which Deaths Are More than 5 Per Cent Below Normal

1. France and Italy	51° to 74°
2. The northeastern quarter of the United States	51° to 71°
3. California	55° to 75°

4. The southeastern United States .... 60° to 63°
5. The dry interior of the United States ...... 57° to 73°
6. Colored people in the United States ...... 53° to 78°

In each of these cases the central part of the area of high vitality lies not far from a mean temperature of 64° and a mean relative humidity of 80 or 85 per cent. In each case there is a tendency for the lines to converge toward the right at high temperatures, which means that hot and very damp weather is not favorable, as everyone knows. To the left a similar tendency toward convergence or in some cases a complete closing of the lines indicates that although a certain degree of dryness may be favorable in hot weather, too much is bad. Another notable feature is that toward the top of the diagrams above the area indicating the most favorable conditions the lines are closer together than they are toward the bottom. In other words, temperatures that are too high have a worse effect than those that are too low. Again it is noticeable that at low temperatures the lines tend to swing from a horizontal position on the left to a vertical position on the right. This means that in cool weather moist conditions are decidedly better than dry. In this respect the diagrams are surprising, for it is rarely realized that there is any such pronounced difference between cold damp weather and cold dry weather. In fact, the vast majority of persons suppose that dry weather is the best. There is no questioning the diagrams, however, for, as has already been said, they are based on millions of deaths. Moreover, the same features appear in each of the five areas into which the United States is divided, in France and Italy when taken separately as well as together, and in individual cities such as New York and Stockholm.

One of the most striking features of the diagrams is that although their general form is alike and although they all show substantially the same optimum, the lines are far apart in Figure 70, the diagram for the northeastern United States, nearer together in Figure 69 for France and Italy, and nearest of all in Figure 71 for California. Between the northern and southern parts of both France and Italy there is the same sort of difference, the lines being farther apart in the northern diagram than in the southern. This means that while people of all these regions are strongest and most energetic at essentially the same temperature and humidity, a departure from these apparently ideal conditions is especially harmful in southern Italy, southern France and California, and does much less harm in northern France and Italy and especially in the northeastern United States. This at first sight seems puzzling. The climates that are generally considered best for invalids actually show greater extremes in the death rates than do the more rugged climates. This happens not only in southern California where there are many invalids, but in San Francisco and southern Italy where there is no influx of such people.

The explanation is apparently found in the variability of the different climates. One type of variability is the change from season to season. Where that is strongly developed people appear to acquire a power of resistance unknown where uniformity prevails. The effect is like that of exercise. The people whose bodies are exercised by frequent transitions from one set of weather conditions to another are more healthy and energetic than those who live where there are no changes. The benefit of a climate like that of southern California comes not so much from staying there year after year as from going there. Since the temperature never departs far from the optimum, people who come from other regions usually receive immediate benefit like that which they experience in their own homes during the favorable months of spring and fall. Add to this the advantages of rest, novelty, interesting scenery, out-of-door life, and freedom from undue extremes of temperature, and it is not surprising that people wax enthusiastic over the California climate. Nevertheless that region lacks one of the greatest elements of an ideal climate.

That element takes the form of frequent and moderately strong variations of temperature from day to day. Piece work in factories, the marks of students at West Point and Annapolis, and especially the deaths in New York City day by day for many years all show that at all seasons of the year a drop of temperature is stimulating *per se* while a rise is depressing. This is true regardless of the actual temperature. Even if the temperature averages as low as 25°, which is very unfavorable as appears in Figure 70, a further drop to 18°, let us say, is accompanied temporarily by an increase in the efficiency of piece workers, an improvement in the marks of students, and a decline in the death rate. If the low temperature continues, these good conditions promptly disappear, but they are very distinct while they last.

A corresponding rise of temperature, from 25° to 32°, let us say, is accompanied by exactly the opposite effect. The efficiency of factory workers declines, the marks of students fall off, and the number of deaths increases. This happens in spite of the fact that the actual temperature is now more favorable than before. If that temperature continues, physical work, mental work, and mortality soon adjust themselves to levels more favorable than prevail under lower temperatures, but the *rise of temperature itself* upsets this adjustment temporarily. The conditions resemble those of a bath. If one had to stay in a bath all day a fairly high temperature would doubtless be advisable. A temperature as low as 40° or even 60° F. might lead to fatal illness. But a brief plunge into water of the lower temperature is highly stimulating, while even a few moments in a hot bath produces a feeling of relaxation.

The most stimulating of all baths is like the most stimulating weather. It is a Swedish bath in which first hot and then cold water are poured over the bather in rapid succession. A man goes into such a bath tired and depressed, with hanging head; he comes out fresh, alert, erect. Several lines of evidence show that frequent changes of temperature from day to day produce an analogous effect. The strongest evidence is found in a study of daily deaths in New York City by the Committee on Atmosphere and Man of the National Research Council of the United States. A most careful analysis by means of climographs and otherwise shows that at high temperatures an average change of 4° F. in mean temperature from one day to the next is the best condition. At lower temperatures this optimum interdiurnal change increases to 6° or 7° F. At all temperatures a very low degree of interdiurnal change is worse than a high degree, and a high degree in turn is worse than the intermediate or optimum condition. So pronounced are these differences that interdiurnal variability of temperature appears to rank almost with mean temperature and relative humidity as a factor in human health and energy. Ordinary storms of the type experienced in the United States, Europe, and Japan are the greatest agency in producing the kind of moderate variability which is most stimulating.

Thus far we have been dealing only with people of European races. We have seen that in France, Italy, Sweden, and five different sections of the United States, the best health and greatest energy are found under essentially the same conditions. People of Mediterranean race in warm South Italy respond to climatic conditions in essentially the same way as people of Nordic race in cool Sweden. According to data given in *World Power and Evolution* the optimum temperature for Stockholm averages as low as 60° for day and night together and that for South Italy 63°, but such a difference is within the limits of probable error of our data. It cannot compare in magnitude with the difference between the two

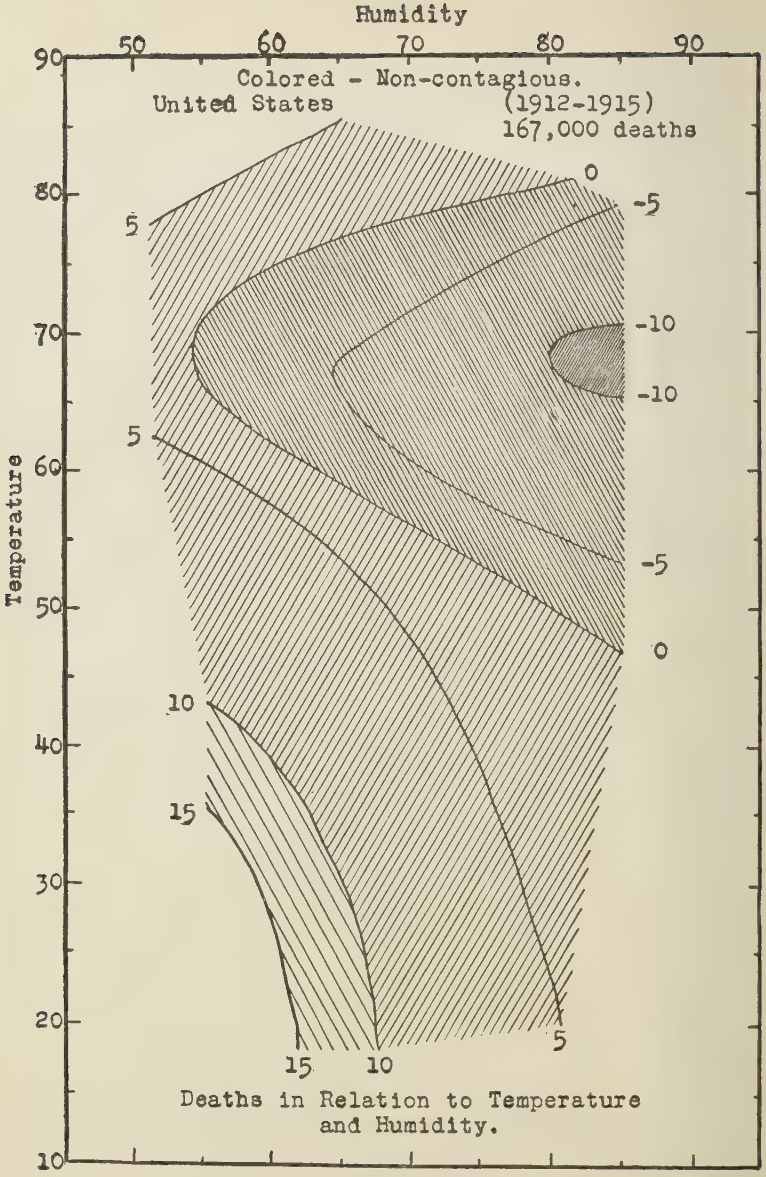


FIG. 72.—Climograph of deaths of colored people in the eastern United States, 1912-1915. Non-contagious diseases. Departures from normal in percentages of normal. Based on 167,000 deaths in all cities and states for which separate figures for whites and negroes are given in the Census Reports, with the exception of New Orleans.

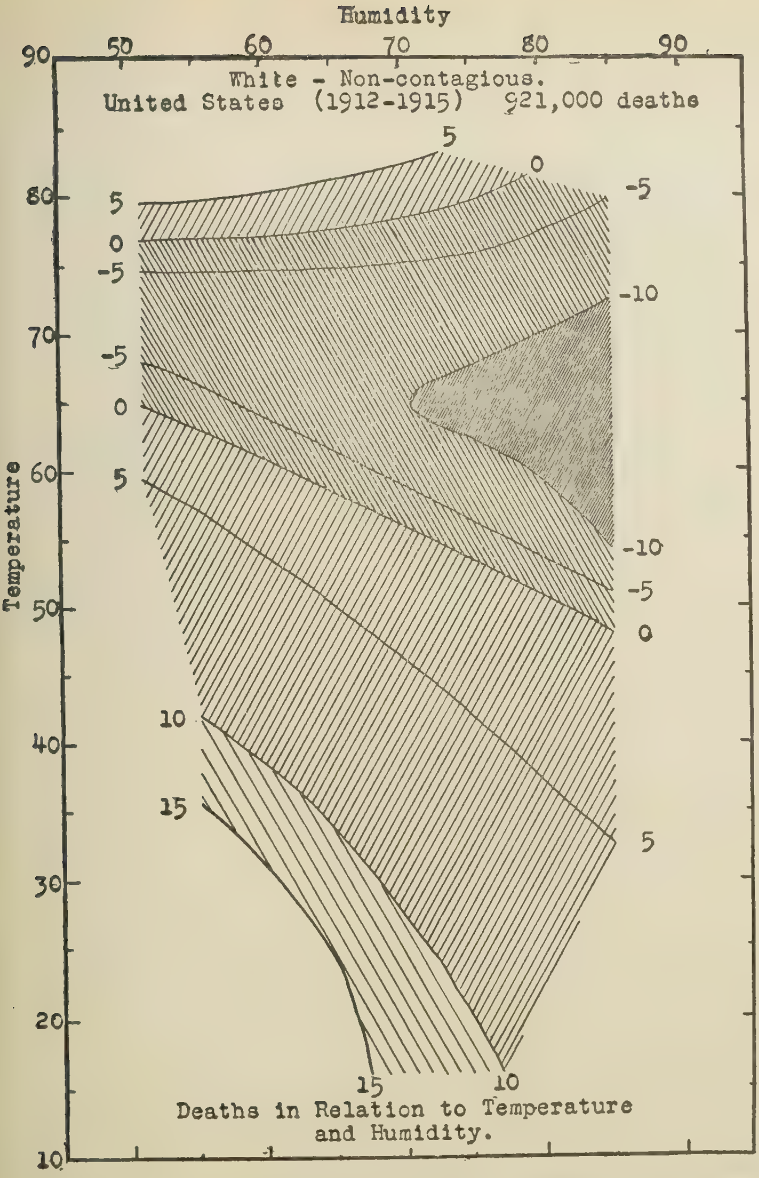


FIG. 73.—Climograph of deaths of white people in the eastern United States, 1912-1915. Non-contagious diseases. Departures from normal in percentages of normal. Based on 921,000 deaths in all cities and states for which separate figures for whites and negroes are given in the Census Reports, with the exception of New Orleans.

climates. In South Italy the average monthly temperature ranges from 45° in January to nearly 80° in July; in Stockholm from 27° to 62°.

It is surprising enough to find such an agreement among the races of Europe. It is still more surprising to find that in Japan the optimum temperature of an Asiatic race is almost identical with that of Europeans in general, namely 64°. But the most surprising thing is that the optimum of whites and negroes in the United States differs so little. This is illustrated in Figures 72 and 73. Figure 72 is based on all the reported deaths of colored people from non-contagious diseases in the states of Maryland, Virginia, North Carolina, and Kentucky, and in all the cities, both north and south, where deaths of negroes are reported in the Census tables from 1912 to 1915. In view of the diverse location of the places whose data are considered the number of negro deaths is small, only 167,000, so that accidental and local circumstances cause great irregularities. Nevertheless, it is clearly evident that the zone of fewest deaths ranges from about 53° to 78°, which is essentially the same as in Figures 69 to 71. Light areas indicating many deaths are increasingly prominent at low temperatures and low humidities, and also at high temperatures and high humidities. The absolute optimum lies at 68° or only 4° higher than in Figures 69, 70, and 73, and not so high as in Figure 72 for the Pacific coast.

Figure 73 is based on exactly the same places as Figure 72, but it illustrates white deaths instead of colored. It differs from Figure 72, however, because the number of deaths is much greater, being about 921,000. Moreover, the relative importance of different places varies much. For instance, in New York City there are only about 2,500 colored deaths per year, while white deaths number nearly 70,000. In North Carolina, on the contrary, the white and the colored deaths in the towns for which statistics are available each amount to bout 4,000 per year. In spite of this, the two diagrams show he same general features, and a difference of only 4° is the ptimum temperature. This is highly significant. It shows hat in spite of the great outward difference between whites nd negroes, the two races are fundamentally alike in their limatic response. Even though his ancestors lived in Africa or thousands of years, the negro appears to have acquired ittle more than an external adaptation to a hot climate. His ase is even more striking than that of the Finn, who has ived in a cold climate for many generations. The average emperature in the places where these two races have spent most of their lives differs by about 40°. Nevertheless, the emperatures at which each is most healthy and energetic differ by no more than 8°. It appears that not only the Nordic, Mediterranean, and Mongoloid races are almost alike in their response to climate, but even the negro joins them. It seems scarcely going too far to query whether all mankind may not show nearly the same adjustment to one special kind of climate. Men may have black skins to protect them from the heat of the tropics, or fair skins adapted to a cloudy, northern home, but so far as actual temperature and humidity are concerned they may not be essentially different. Possibly man's adjustment to climate is somewhat like the temperature of the blood, which is almost unchangeable, no matter in what climate man may live. Possibly this seeming uniformity in man's adaptation to climate may indicate that the conditions under which he is now at his best are those under which he took the most important steps in his final physical evolution, and acquired his present invariable inner temperature.

In this connection it is important to note that among white men the best conditions for mind and for body do not appear to be quite the same. Variability seems, if anything, to be even more stimulating to mental than to physical activity. Tests of school children made by Lehman and Pedersen in

Copenhagen and my own study of the marks of about 1,600 students at West Point and Annapolis indicate that mental activity is greatest at a temperature decidedly lower than the optimum for physical energy. For negroes the difference, as indicated by daily tests of twenty-two students at Hampton Institute for sixteen months, is much less. Perhaps this indicates that after the separation of the white and negro races the whites endured a period of low temperature and of climatic stress which modified their mental response to temperature, but the negroes were not affected so much because they had gone too far south.

If the conclusions here presented are sound, a knowledge of the temperature, humidity, and variability of any region enables us to determine the approximate effect of its climate upon man's physical and mental energy. It is thus possible to prepare a map showing the distribution of either kind of energy or of the two combined. Such a map, in which physical and mental energy are regarded as of equal importance, is shown in Figure 74.[2] The map is subject to correction when fuller data are available, but that will not change its main outlines. The heavily shaded areas are those of great energy. The agreement of these areas with the places where civilization is highest is too marked to escape notice. In order to bring the matter more clearly before us, Figure 75 has been prepared. This is a map showing the distribution of civilization according to the opinion of fifty competent judges in fifteen different countries. The judges have been grouped in such a way that the opinion of each of five groups, namely Americans, British, Teutonic Europeans, Latin Europeans, and Asiatics, has equal weight. The agreement of the two maps is surprising. It indicates that at the present time the distribution of climatic energy and of civilization is almost identical. Such differences as are discernible occur almost wholly where exact information is lacking or where the presence of Euro-

---

[2] The map is fully discussed in "Civilization and Climate." 3d ed. New Haven, 1924.

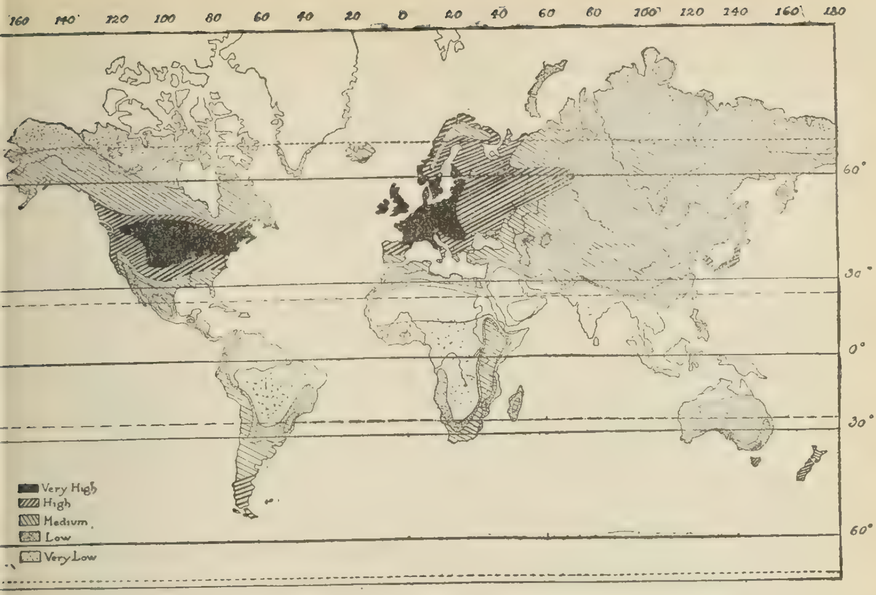


FIG. 74.—The distribution of human energy on the basis of climate. From "Civilization and Climate."

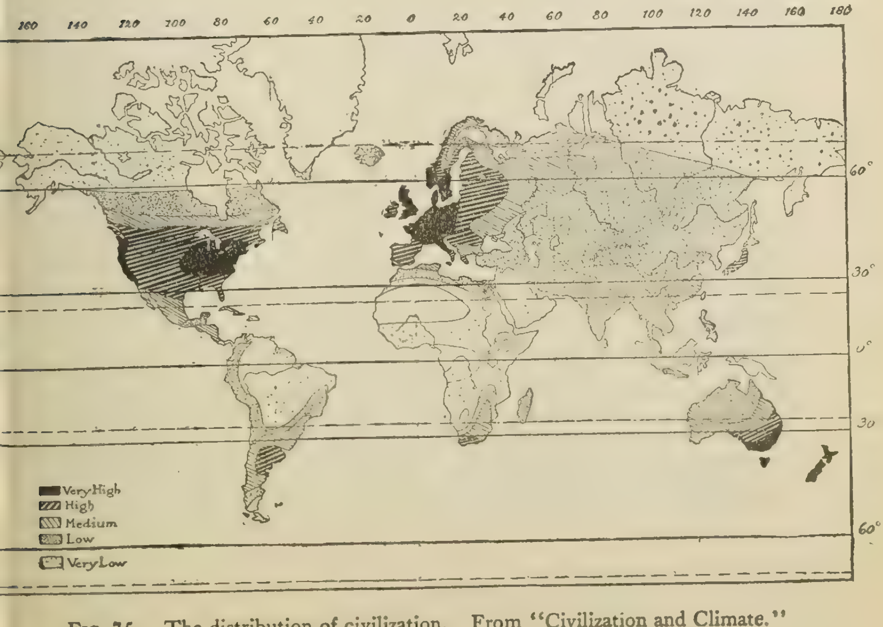


FIG. 75.—The distribution of civilization. From "Civilization and Climate."

peans as colonial rulers raises the apparent standard of civilization.

This brings us to the climax of our discussion. At the beginning of this chapter we saw that human progress, that is, the growth of civilization, depends in apparently equal measure upon inherent mental capacity, material resources, and energy. We then saw that although inherent capacity has no relation to present climatic conditions, it is closely intertwined with those of the past, and especially with the migrations and natural selection arising in response to climatic pulsations. We also saw that although some resources like the metals and coal occur without respect to climate, their utilization is largely controlled by climatic conditions, while the vast majority of resources depend directly upon climate through its effect on vegetation. Finally we have seen that human energy, even more than either of the other conditions, appears to be dependent directly upon climate through physiological effects upon man's body. Thus in the evolution of civilization, as in the broader field of the evolution of life, the most obvious external factor, although by no means the only one, appears to be climate.

STEPS IN THE EVOLUTION OF CIVILIZATION

Fire and the Coldward March of Civilization. In the light of the preceding conclusion let us briefly examine some of the great steps in the evolution of civilization. Three of the earliest and greatest steps were the invention of tools, the invention of speech, and the discovery of the use of fire. As to the relation of tools and speech to climate, nothing definite can yet be said. They probably became a part of man's cultural inheritance so early that he still lived in his primeval home, and had perhaps not begun to differentiate into races. If that is the case, the climate was presumably of the kind which unclothed, fireless, and perhaps shelterless savages would find comfortable. The best climate for such people would apparently be one where the temperature averages not far from 70° at all seasons, but yet has a fair degree of variability. The nearest approach to such a climate is by no means found in equatorial regions but at a distance of 25° or more to the north or south. Even there, however, although the winters are admirable, the summers are much too long and warm for the best health and greatest efficiency. Now mankind happens to be so constituted that up to a certain point he can endure too much heat more easily than too little. Among naked savages, for example, a temperature of 90° is far less uncomfortable than one of 60°. Therefore unless people possess artificial means of warming themselves they tend to live in regions that are too warm rather than too cold. This retards progress, for people usually overcome the effect of adverse temperature by inactivity rather than by activity.

The introduction of fire changed all this. In conjunction with discoveries as to clothing and shelter, it enabled people to be comfortable in cool climates. It thus led to an advance in civilization in three distinct ways, first, by stimulating further inventions, second, by enabling man to live in cooler and more stimulating climates and, third, by segregating the more competent fire-users from the rest of the population. The perfection of methods of kindling a flame, the discovery of cooking or of making pottery, and the invention of the hearth to replace the bare ground as a place for a fire were among the earliest of the inventions which were rendered possible by the discovery of how to use fire. A later invention made it possible to carry off the smoke by means of a chimney. Further perfection of this device brought into existence an efficient fireplace which eliminates smoke and throws at least a moderate amount of heat out into the room. All this sounds childishly simple to us, but when the first crude fireplace was made by setting up a few stones it represented as high a degree of inventiveness as does the modern gas furnace in our most expensive houses. The enclosed oven made of mud in China, the metal stoves of Europe, and central heating by means of furnaces all represent stages in this same long process of invention. Even the modern electric cooker with its automatic heat controls involves not a whit more exercise of the inventive talent than did the earliest clumsy systems of making fire by rubbing sticks together or striking stone on stone. From first to last fire has always been a tremendous stimulant to human invention, a challenge to men to find new ways of utilizing it.

For our present purpose the important point is that this challenge tends to be most intense and productive under certain definite climatic conditions which have gradually changed with the lapse of the millenniums. In the earliest days the naked savages who first took up the use of fire must have been especially likely to do so in the cooler parts of man's primeval habitat. Of course this is pure inference, but it is based on some of the fundamental traits of mankind. The man who often becomes a little chilly in winter or at night is assuredly more likely to appreciate a fire than is the one who is almost never cold. The one who finds himself chilly for several months during a cool season must be more stimulated to maintain a fire day after day and find methods of kindling one than is the man who rarely or never wants a fire and to whom it is usually a source of discomfort. If this be granted it follows almost inevitably that in primitive times before fire was used universally there must have been a period when the use of this greatest of human tools was far more common on the cooler borders of man's habitat than in the central parts that were warm all the time. Thus the stimulus to invention which we have just discussed must have been stronger in latitude 25°, let us say, than in latitude 10°.

The stimulus derived from fire doubtless caused people to set their wits to work devising methods not only of making and keeping fire and of using it for warmth, but of utilizing it for cooking. When once mankind appreciated the fact that heat would make all sorts of vegetable and animal products more palatable and would also help to preserve them, there must have been a tremendous impulse to experiment with every kind of living thing and see how much it could be improved by roasting. At some time a lucky accident presumably suggested the idea of boiling food in water. Perhaps a hot stone was dropped into a gourd of water wherein some sort of food was being washed, and thereupon the water boiled and a new and delectable way of cooking food was discovered. At any rate something occurred which stimulated people to make experiments for the sake of devising vessels in which water could not only be kept but boiled. The growth of the great art of pottery making, one of the most important in the whole realm of human technique, must have been greatly stimulated by the desire to cook food as well as by the possibility of hardening clay in fire which sooner or later was discovered. If fire had done nothing more than stimulate such inventions, it would presumably have caused a concentration of activity and hence an exceptionally rapid growth of civilization on the cooler borders of man's early habitat.

But fire did far more than this. It enabled primitive man to move into regions which had hitherto been too cool for habitation. With fire as their tool primitive men little by little became able to live and reproduce their kind in cooler and cooler regions. Each of the inventions and discoveries which led to our modern furnaces, as well as others like the art of melting ore into iron and making glass by melting sand, was a step in what GilFillan calls the "coldward course of progress," and Stefansson the "northward course of empire." Iron tools permitted man to cut trees in abundance for fuel; glass at a much later period allowed him to use his leisure in cold weather for all sorts of useful purposes. It permitted him to have light without opening doors or shutters and thus making his hands so cold that they lost their skill. The idea of using fire for artificial light must have had a similar effect. Not only did it presumably stimulate the keener minds to make all sorts of new devices for getting better light, but the light itself robbed the long nights of their terrors, drove off wild beasts, and made it more and more possible to utilize the long hours of winter darkness in middle and high latitudes for work instead of sleep. Thus in all sorts of ways fire not only allowed mankind to utilize climates that had hitherto been too cold, but in those new places stimulated the human faculty of invention even more than in the cooler parts of the earlier habitat. In addition to all this, and perhaps still more important, the increasing application of fire to human affairs enabled men to enjoy a greater direct climatic stimulus, for it permitted them to live in cooler and more variable climates. Thus the new stimulus toward invention and progress was reenforced by an increase in energy. Climate and fire apparently coöperated to cause the centers of civilization and progress to migrate slowly from warmer to cooler districts.

Still a third factor must have coöperated toward this same end. Who uses a new invention? Is it the dull, the stupid, the unprogressive, the unadaptable, the lazy, the conservative? Not a bit of it. Every great new invention or idea is at first the property of exactly the opposite kind of people. In America there is an automobile for every family on an average, but there are still plenty of families without automobiles. Some of these are highly competent, but on an average it seems evident that those who have automobiles are decidedly more competent than those who do not. In other countries, where automobiles are far less common than in America, this is still more true. The same is the case as to radio outfits, washing machines, power lawn-mowers, and aeroplanes. The people who get the benefit of these new inventions are a highly selected group more capable than the average. Exactly the same was presumably true of fire. It required patience, effort, and skill to keep a fire going day after day and month after month. Yet that was necessary in the early centuries or millenniums when people apparently used fire but could not kindle a flame, and had to get new fire from some natural source such as the lightning. It was no small chore to provide wood for a fire day in and day out when the only tools were bits of stone. It required patience also for a hungry family to coax the wood into a blaze and cook the freshly killed meat instead of sitting down at once and eating it raw as the neighbors did.

Such sacrifices were worth while in many ways, and among those ways the biological was the most important. By this I mean that fire gave to its users a tremendous biological advantage. It helped them to resist diseases due to cold and exposure; it made it possible to preserve food longer than had hitherto been the case; it helped to drive away wild animals and enabled people to prepare better weapons wherewith to kill game. Most of all it greatly increased the food supply not only by rendering many plants edible that had formerly been of no use, but by increasing the nutritive value of certain plants which were already staple foods. All this presumably meant that in the families of the fire-users the deathrate from disease, hunger, exposure, and the like was lower than formerly or than among the neighbors who were too stupid, lazy, or unprogressive to use the new tool. Unless the whole science of genetics is a myth the children who were thus preserved in the more capable families of the fire-users must have been innately superior to the children of the more backward parts of the community. Thus an increase in their number must have tended to increase the proportion of people whose brains possess the higher type of organization, thus raising the average level of mentality.

A still more fundamental effect must have arisen in the case of the people who migrated into regions that had formerly been too cold for human occupation. Such people must have belonged to the fire-using group. They must also have been subjected to the selective processes which we have seen to be connected with all migrations. Thus the survivors, especially during the earlier, more difficult stages, had presumably run the gauntlet of a double process of selection based on migration as well as fire, and must have been correspondingly superior to the average people of their time. When once the hardships of migration were overcome they doubtless behaved like modern migrants and had larger families and raised more children than did those who remained in the old home. Those children had to marry young people of their own kind, for there were no others to marry. Thus the innate quality of the migrants was preserved. It must have been even higher than that of the people in the cooler part of the old habitat. Yet those people in turn, as we have seen, must have tended to become superior to those in the warmer regions where fire was not greatly desired. Thus the stimulus to invention, the activity and health arising from climatic stimulus, and the innate quality of the people all appear to have received an impetus through the use of fire and the consequent migration of mankind into cooler regions. Only when they reached climates that are colder than the optimum for any given stage of civilization does there seem to be any reason why this process should cease.

Rise of Agriculture. During the whole course of human history few steps of progress have been more important than the invention of the art of agriculture. It is impossible to say exactly where agriculture arose. Perhaps it developed in different ways in many different regions. The great staples of agriculture are the cereals—wheat, barley, rice, millet, corn, rye, and oats. The majority of these are of subtropical origin. Even rice, which supports more people than any other one kind of food, was probably first cultivated in China. Today two thirds of the world's rice is raised outside the tropics. Corn may be of tropical origin, but if so it probably came from a high altitude and a relatively cool climate. Millet, which well-nigh rivals maize in the number of people it supports, is of great importance within the tropics, but apparently it originated farther north in a subtropical climate, such as that of Egypt. The other grains all appear to have originated in regions well beyond the limits of the tropics. Thus at the very beginning of agriculture the people who lived outside the tropics had an enormous advantage over those within the tropics, for they had by far the best kinds of plants.

When these plants were first cultivated the people living in moderately warm plains with plenty of water part of the year and a long dry season possessed a still further advantage. They, and they alone were able to find broad tracts where they could easily get rid of the native vegetation and replace it by the cereals. That is why irrigation is so important. On many subtropical plains that are subject to intermittent flooding the vegetation consists mainly of bunch grass that can easily be pulled up, thus leaving the land ready for crops. As soon as the flood subsides the moist land is soft, weedless, and ideal for crops, even though the farmer has no tools except his hands. This is the reason why the great civilizations of early times arose in the fertile plains of Egypt, Mesopotamia, northern India and China.

It is hard to overestimate the effect of irrigation upon the early progress of civilization. Because of the necessity of making ditches and reservoirs, and of having everything ready when the water is turned on to a field, the power to prepare consciously for the distant future is enormously stimulated. The man who depends on irrigation cannot neglect his fields, for a week of carelessness may cost his whole crop. He must learn, too, to live at peace with his neighbors. If men who use the same stream for their water-supply quarrel with one another and break down one another's dams and ditches the chances are that all will suffer famine. They must agree, and therefore must organize a well regulated system of government. The fact that in irrigated regions many people live close together on a small area also tends to cause society to be thoroughly and wisely organized. Moreover, the mere fact that water is precious leads to economy in its use and to intensive agriculture. Hence man's faculty for planning and for devising new schemes to increase his crops is constantly stimulated. How far this stimulus may lead is shown in the case of the Hopis of Arizona. Could there be any higher development of agricultural science than their way of putting a seed into the midst of a ball of wet clay and burying it in the dry sand? The stalk of corn that grows from such a seed may be only a foot or two high, but it bears an ear with a hundred grains to replace the one grain that was planted. In milder environments where there is plenty of rain the stimulus toward such inventions is by no means so great.

Agriculture, like fire, gave to the people in certain types of climatic environment not only a great stimulus toward the development of new methods of working and getting a living, but a great impetus toward biological improvement. It made it possible for certain areas to support a score or two of people per square mile where formerly they had supported only one. Thus the number of people increased enormously. But what kind of families profited most in this way? The stupid, conservative, unadaptable ones who would not take the trouble to practise the new method? Not at all. Those people still got a living by hunting, fishing, and gathering wild seeds and the like. Their numbers therefore remained unchanged. But the people of keener minds and more progressive temperaments who were ready to make experiments, do some extra work, and look to the future to repay them for the work of today—those were the ones who increased and multiplied. When such people were segregated in the limited agricultural areas it seems biologically necessary that to a certain degree their descendants should be born with temperamental aptitudes slightly different from those of the non-agricultural people.

Taming of Wild Animals. The taming of wild animals like the first development of agriculture, was inevitably limited to certain definite geographic regions. It must have stimulated man's powers of invention in the same way as did fire and agriculture, and it must likewise have segregated progressive from unprogressive people, and helped the progressives to increase in number more rapidly than the others. The dog was apparently the first domestic animal. His contribution to civilization, however, is slight, for instead of lifting man out of the hunting stage, he preserves it. If the hunter becomes a tiller of the soil he does not want dogs, for he no longer has a frequent surplus of meat which will spoil if the dogs do not eat it. While he remains a hunter, however, the dogs not only help their master to find wild animals, but serve as a reserve supply of food in times of scarcity. Among the American Indians no delicacy was formerly more esteemed than a fat young puppy. The taming of the dog was in itself no great feat. It was easy to bring home a wild puppy, which grew up as tame as though its ancestors had long been domesticated. This, however, was perhaps the step which led to the domestication of other and more useful animals. It probably did not occur within the tropics, for today the wolf-like creatures from which the dog is supposed to be descended do not appear to be found within twenty-five degrees of the equator.

Other domestic animals far surpass the dog in utility. Lowest among these stands the pig. This creature is highly useful as a source of food, but cannot easily be domesticated unless the art of agriculture is well developed, for it is not readily herded, and its food is primarily the products of agriculture rather than grass. Therefore, though the pig might have helped civilization, it never had much chance, for before it was kept in large numbers the tillage of the ground had probably done all, and more than all, that the pig could do in this line. So far as climate goes it might have been domesticated almost anywhere from the equator to the temperate zone.

The horse, ass, ox, sheep, and camel stand in a different category from the dog and the pig. Aside from agriculture nothing perhaps surpassed their domestication as a stimulus to that sense of ownership and feeling of responsibility which are among the most essential prerequisites of high civilization. As soon as herds were in his care, man was compelled to watch them day by day. Carelessness was fatal. He must defend them from wild animals, drive them to new supplies of grass and water, and plan to sustain them through the winter. Not only did the more intelligent members of the primitive community in certain favored areas thus become property owners by reason of their beasts, but their food supply was enlarged so that they themselves were able to increase in numbers to a degree utterly impossible while they still depended on the chase. Therefore the contact of family with family greatly increased. That necessitated either war and destruction, or some kind of mutual agreement whereby was laid the basis of a rudimentary social and political organization. In either case it meant a new stimulus toward man's use of his powers of invention. At the same time, the segregation of the cattle-raisers in certain localities presumably had the usual effect of raising the general biological level of the pioneers in the cattle raising areas to a level above that of the people whose conservatism, stupidity or lack of opportunity caused them to remain in the more primitive stage of hunters and gatherers of the wild products supplied by nature.

All this can scarcely have happened in all parts of the world alike. The grass-eating animals of the horse, ox, sheep, and camel families, which alone are of much use to man, live naturally under certain strictly limited climatic conditions.

All of them are natives of the subtropical grasslands of central Asia or North Africa twenty-five to forty degrees from the equator. That is where they appear first to have been tamed. But that is also the region where climatic pulsations appear to have had the greatest effect in causing the concentration of selected migrants who were forced out alternately from glaciated Europe and dessicated Asia. That, too, is one of the regions where the climate and vegetation most favored the development of early agriculture. We seem to see an astonishing concentration of advantages in this particular part of the world.

Discovery of Use of Iron. Long after the use of fire, agriculture, and domestic animals had become well-established another epoch-making discovery led to the use of iron. This discovery required the concurrence of four important conditions, all of which are much less likely to occur within the tropics than without. First, there must be bits of ore lying about where fires are likely to be made. Of course this may occur in any part of the world, but it is far less likely to happen in a warm, moist, tropical climate than in one that is drier and cooler. For one thing the tropical soil is generally so deep that rocks are rare. In the next place the fires must be hot enough and of long enough duration to melt the ore. This, too, may occur within the tropics, but is much less common there than in colder climates. In warm regions cooking is apt to be done over small fires that do not make people uncomfortable, or else in pits dug in the hot ashes; and the temperature is rarely high enough to melt iron ore. Farther north, however, where the winters are chilly, huge fires must have been common from the earliest times. There, too, in the fairly dry areas many stones lie on the surface almost everywhere.

The next necessity is that when some bits of ore happen to be melted in a particularly hot fire a man of unusual genius should be present and observe the molten metal. This might occur anywhere, but we have already seen reasons for believing that intellectual alertness is fostered in fairly cool climates more than in others. Finally, the fourth requisite, and much the most important, is that the man of genius have the zeal and determination, as Darwin puts it, to bring to fruition the ideas engendered by his observations. A single mind, however, is not enough to consummate a great discovery. It is necessary that the generation of men who live with the genius should be "in a mental mood to receive the new invention or discovery." That mood, together with the necessary energy on the part of the genius, is rarely found within the tropics. It is common in regions blessed with a stimulating climate. Thus each of the conditions controlling the discovery of the art of smelting is so much stronger outside the tropics than within them that it seems highly probable that the art arose in an extra-tropical climate.

It is generally supposed that the use of iron originated in North Africa perhaps 6,000 years ago but the date is very uncertain. This is consistent with our conclusions, for at the dawn of history North Africa appears to have had a more rainy, stormy, and stimulating climate than now.

From our present point of view a much more important consideration is the fact that the invention of the art of using iron enabled mankind to migrate into new regions where the climate is especially stimulating. The best climates for human health and activity are also especially favorable for mixed forests composed largely of broad-leaved trees such as naturally prevail in central Europe and the northern United States. Until iron tools were invented it was almost impossible for mankind to occupy such areas in any large numbers because of the difficulty of clearing the forests. Another highly favorable type of climate is characterized by a dense growth of prairie grass, forming a tough sod. Such regions, too, could not be occupied by an agricultural population until not only draft animals but iron plows were available for breaking and turning the heavy turf. Thus it is probable that the art of preparing iron not only arose where the climate was moderately dry and cool, but that it was an extremely important factor in permitting mankind to migrate to the best climates of all and there multiply exceedingly. Bear in mind that iron, like fire, must have been selective in its action on man. The more intelligent families or larger groups were the ones to use it. These in turn were enabled to multiply because they could procure more food than hitherto and protect themselves from enemies. Moreover, it was from among such people that the especially energetic, adaptable, pioneering type migrated into new lands, cleared the forests, and plowed up the grasslands. In these new lands this highly selected type was able to multiply enormously, thereby taking another step toward the production of a race or stock that is biologically as well as culturally advanced.

Such biological conditions interplay most delicately with the geographic and cultural elements of human progress. After mankind has reached a fairly high stage of development the kind of agriculture which most stimulates him to new inventions and new levels of achievement is the kind which prevails in the very same regions where the climate is most stimulating. There each farmer lives on his own independent farm. He may not have the stimulus of close contact with his neighbors which is found in irrigated subtropical regions, but he has the great stimulus of being wholly independent and of being constantly urged to meet his own needs. Moreover, he must be industrious and alert to a degree demanded of no other kind of farmer. The constant variety of weather to which he is subjected demands that he shall be ready to cut or harvest his hay instantly when the right time comes. He cannot put off cutting his grain as can the subtropical farmer, for when once it is ripe the rain may come and ruin it. In the fall, no matter how overworked and tired he is, he is forced to gather his crops before they suffer from a sudden frost. Thus while tropical agriculture is a help toward civilization, and that which prevails in subtropical regions is still more so, the agriculture of the stormy temperate zone is preëminent in this respect. But this last type comes into existence only after a long process whereby the mutual reactions of climate and other geographic conditions upon human germ-plasm and human powers of invention have gradually driven the centers of greatest progress from the borders of the tropics to the cooler latitudes where storms are frequent, rain falls at all seasons, and the climatic stimulus to health and activity is at a maximum. Perhaps some day some other type of agriculture, such as that of tropical plantations, will demand still greater foresight and energy, but that is too hypothetical to be considered as yet.

The Ecological View of Civilization

We have called this chapter *Climate and the Evolution of Civilization.* We might perhaps more truly have called it *The Interplay of Geography, Biology, and Human Invention,* or better still *The Ecology of Civilization.* Our thesis is that while civilization is the product of the human intellect and emotions acting through all sorts of inventions, discoveries, ideas, and institutions, this action is greatly modified by geographic environment. Even if the human mind were everywhere the same it would produce different results in different parts of the world for two main reasons. In the first place the conditions of climate, soil, minerals, waterways, topography, vegetation, and animal life cause great local differences in the materials upon which man's intellect must play. The same mind confronted by different material resources is bound to produce different results. In the second place human activity, both physical and mental, varies greatly in intensity from place to place and time to time according to physical conditions such as food, clothing, shelter, disease, and climate. Among these physical conditions climate is the most important not only because it often exercises a decisive effect upon the others, especially in primitive times, but because it also exercises a remarkably strong direct effect upon health and vigor.

But the human mind does not appear to be exactly the same in all parts of the world. There appear to be hereditary differences in the brain which manifest themselves in distinct types of intellect and especially temperament. Although some anthropologists and others still assert that all races are innately alike such a position seems to us too untenable to demand much attention. The various breeds of dogs certainly differ in mental inheritance as L. F. Whitney[3] conclusively shows. Some breeds with no training whatever will follow a trail by the sense of smell, barking as they run. It is almost impossible to train them to do otherwise. Other breeds can never be trained to act in that way, but while still puppies and without training will come to a dead stop and silently "point" toward game that happens to be sighted. Some breeds again, no matter how they are trained, will endure all sorts of annoyance from children and others without losing their self-control. Other breeds become annoyed at once and begin to bite, and can scarcely be trained to do otherwise. The significance of all this lies first in the fact that all members of each breed show in general the same mental characteristics. In other words a distinct mentality goes with each well defined breed. In the second place, we know that in some instances diverse breeds have had a common origin, but their strong mental differences are now fully hereditary.

---

[3] Eugenics, vol. 2, 1929.

If the processes of selection can produce such mental differences in breeds of dogs, it seems unreasonable to deny that they can do likewise among breeds or stocks of men. We know that selective processes have actually been at work upon man just as upon dogs. Few people who have seen much of the world or who have made tests of mental ability and temperament entertain any doubt that races as a whole and especially groups within each race differ from one another in intellect and temperament. Of course such differences are especially evident among individuals, but in a broad way and to a less degree they are also apparent among large groups of people and even among the largest groups known as races.

If it be granted not only that there are great differences of physical environment from one part of the world to another, but also that innate mental differences can be strengthened or weakened by biological selection and segregation, it seems inevitable that mental evolution must accompany the development of civilization.

Even if no group differences of mentality existed originally they would presumably be bound to develop under the combined influence of geographic environment and the varying cultural conditions which are localized in one region or another. Mutations may play a part in this but the main agency which we can actually see in operation is the natural or social selection of individuals of similar mentality and their segregation and further selection long enough so that certain traits become fixed. On this basis we discern in human history at least three major tendencies in which geographic environment has played an important part. One involves a general northward or coldward trend not only of the centers of civilization and progress, but of racial ability. A second involves the concentration of mental ability in the eastern Mediterranean lands a few thousand years ago, and the third a similar more recent concentration in Europe.

The coldward march of civilization owes much of its strength to the fact that many of the greatest of human inventions have increased man's power to withstand cold but not his power to withstand heat—this is true of fire, clothing, shelter, iron tools, and an endless procession of minor inventions. Each invention of this sort has presumably been used at first by intelligent and progressive people more than by the stupid and incompetent. Such inventions usually enable more people than formerly to live in a given area. They also open new areas to habitation. Hitherto it has been the cooler rather than the warmer parts of the world that have thus become more accessible and habitable. The unusually intelligent individuals or social groups who use the new invention are likely to be the ones to increase in number in the old home and to take possession of the regions that are newly opened. Thus a northward march of civilization into cooler and more stimulating regions seems to go hand in hand with the progress of invention on the one hand and the increase of human intelligence on the other.

The other two great tendencies discussed in these pages apparently illustrate what happens when climatic pulsations are superimposed upon the coldward march of civilization. They are part of a great movement of the centers of human progress backward and forward under the impetus of the vast climatic pulsations of the glacial period and the smaller pulsations of post-glacial times. But material resources have also played their part. The lands around the eastern Mediterranean appear to have been a fruitful nursery of civilization because climatic conditions have given them both material and human advantages to a remarkable degree. On the material side they reaped the benefits of a climate in which they could utilize not only easily irrigated flood plains but the best of all food plants, and the best of animals. Another advantage appears to have been that when civilization was making its first great strides the eastern Mediterranean lands apparently enjoyed a more rainy, variable, and stimulating climate than that of today. Their summers were doubtless too warm, but on the whole the climate was excellent for the stage of progress that had then been reached. Still more important perhaps, was the fact that those lands were the place where selected human types from the desert on the one hand and the cool lands of Europe on the other mingled most fully. Migrations due to the expansion of deserts at some times and of cold stormy areas at others appear alternately to have sent into these favored lands streams of immigrants who had been sifted and strengthened by prolonged and arduous wanderings during many generations. Thus apparently it came to pass that the long, slow and irregular coldward march of human progress was marked by an especially brilliant stage in the lands near the eastern Mediterranean.

In our own day the third great tendency has eclipsed the other two. That tendency takes visible form in the dominance of western Europe and its children across the seas. Such dominance, as we interpret it, is due partly to an unrivalled social inheritance of ideas, institutions, inventions, discoveries, and customs derived from the countries of the eastern Mediterranean. But it probably likewise owes much to two other factors like those which once benefited the Mediterranean lands. The first is that at our particular stage of progress western Europe is almost the best portion of the earth from the standpoint of the effect of climate upon human vigor. There is perhaps no climate which excels that of southeastern England in its healthfulness and its stimulus to vigorous physical work, hard study, and creative mental activity. Paris, Geneva, and Berlin enjoy climates almost as good as that of London, while Vienna, Copenhagen, and Stockholm fall not far behind. The general region in which these cities are included also enjoys certain other great advantages in the form of unrivalled natural facilities for transportation by water and a splendid supply of coal and iron. Such conditions in our day are as important as were flood plains, wheat, horses, and cattle in the days when civilization centered in Mesopotamia and Egypt. Moreover, western Europe like ancient Mesopotamia has enjoyed the further advantage of recent selective migration. In the space of scarcely more than 2,500 years a pronounced amelioration of climate has joined with the use of iron and the general progress of civilization to make it possible for western Europe to support scores or hundreds of times its former population. Most of this vast array of people are descendants of relatively recent migrants from among whom the weaklings, physically, intellectually, and temperamentally appear in large measure to have been eliminated by prolonged migrations. In Europe, as in the lands of the eastern Mediterranean, the progress of civilization seems to have been greatly accelerated through the combined effects of natural advantages and a high type of racial inheritance which owes much to selection through migrations under the impetus of a changing climatic environment.

CHAPTER XII

THE TREND OF EVOLUTION

EDWIN GRANT CONKLIN
PROFESSOR OF BIOLOGY, PRINCETON UNIVERSITY

If in the manner of the Olympian gods we mortals could have viewed from some exalted place the grandest drama which has ever unfolded itself on this planet, namely, the origin and evolution of life, and if in the manner of the modern "movie" we could have seen this drama speeded up so as to bring the whole of it within the sight and experience of any one person, with what surprise should we have watched the marvelous appearances and transformations which at almost every step have marked its progress, and how utterly impossible it would have been to have predicted its future course or from its small and weak beginnings to have foreseen its magnificent developments, its tragic failures, its stupendous successes! What merely human intellect could have foreseen in those earliest protoplasmic particles "the promise and potency of all life," the million species of animals and plants, the monsters of the deep, the giant saurians, the mighty beasts, and finally man? Who could have predicted the marvelous adaptations for nutrition, locomotion, offense and defense, reproduction, sensation, and coördination? Who could have foretold from the earliest reactions of this primeval protoplasm the complicated and subtle behavior of plants and animals and men? Who could have foreseen in these reactions the development of an intellect capable of studying or appreciating, even to the extent of wondering at, this marvelous drama? Who could have foreseen in the earliest stages of the association and dependence of individuals the future societies of ants or bees or men? Indeed, who at any stage in this greatest drama of all time could have predicted the next scene, much less the final ending?

If to human intellect every former stage in this process would have been unpredictable, what likelihood is there that future stages may be predicted? Surely these considerations should weigh heavily with anyone who attempts to forecast even the next step in evolution and they should make it plain that the final outcome is almost as completely hidden from us as it was from the original amœba.

But in evolution, as in the succession of generations of individuals, there have been cycles which have repeated again and again particular principles, problems, and solutions, just as one theme may form the groundwork of a great symphony. All that has been said of the impossibility of predicting the course and outcome of evolution could have been said with equal accuracy of the development of an individual. Who that had not before witnessed the process of development could possibly see in an egg the promise and potency of all that will develop out of it,—the complicated body, the remarkable instincts, the emotions, intelligence, and consciousness,—in short, the personality of a human being? But, owing to the fact that this process of development repeats itself again and again with slight variations, it is possible to predict its general course and outcome though not always its particular details. And so in the case of evolution we find that certain principles and cycles repeat themselves again and again and they make it possible to foresee at least dimly and in ghostly outline the mighty shadows and shapes of the future.

It is in this spirit only and not with the vain imagining that any human being can predict particular events that depend upon so many factors as are involved in the development of an individual or the evolution of a race, that I venture to direct your attention to the trend of human evolution.

Causes and Directions of Past Evolution

And first it is necessary to consider the chief causes of evolution in the past and the most important paths which it has followed, for there is no way of looking into the future except by the light of the past. Unfortunately our knowledge of the causes of evolution is not very complete, but the majority of biologists agree that inherited variations, or mutations, constitute the building materials of evolution, while natural selection, or the elimination of the unfit, is the workman or architect that selects or rejects these materials.

Inheritance and Variation. In order to be of any evolutionary value a variation must be inherited. Thousands of variations occur in organisms which are not inherited; they come with changes in food, climate, use or disuse or other conditions of environment and when these conditions change they disappear. These environmental variations are known as "fluctuations"; they represent changes in development rather than in heredity, modifications of the developed organism rather than of the germ-plasm. On the other hand, inherited variations are caused by changes in the germ-plasm itself. These changes may be of two kinds, (1) those which are due to new combinations or recombinations of old inheritance factors, or what is known as "Mendelism," and (2) those which are caused by sudden alterations in the individual factors or genes, such transformations being known as "mutations."

Formerly these three types of variation, namely, fluctuations, Mendelian combinations, and mutations, were not clearly distinguished, and Darwin assumed that all kinds of variation might be of evolutionary value. We now know that fluctuations have no evolutionary value; Mendelian combinations probably play a secondary part in supplying the materials of evolution, though this part is not negligible; mutations, on the other hand, are the fundamental and initial steps in evolution. Fluctuations and new Mendelian combinations occur in countless numbers; indeed, they may be said to be universally present among organisms; mutations, on the contrary, are relatively rare. Nevertheless, they are by no means uncommon; during the past dozen years Professor T. H. Morgan and his associates have found and studied several hundred mutations in the fruit fly, *Drosophila;* few of these were beneficial changes and almost all of them would have disappeared in a state of nature, but this probably indicates that natural species and varieties are the products of very severe selection, that thousands of mutations have been eliminated where one or a few survive. Many of our numerous breeds of domestic animals and cultivated plants have appeared as mutations, and while we cannot assume that all that have been preserved are intrinsically useful nor that all useful mutations have been preserved, the great number of breeds that have arisen among domestic animals and cultivated plants indicates that useful mutations occur in sufficient numbers to furnish the materials for evolution. (See Chap. XIII.)

There can be no question that the same fundamental principles are involved in the evolution of man as in the evolution of any other organism. Inheritance and variation, fluctuations, Mendelian combinations, and mutations occur in the human race, just as in plants and animals. Furthermore, there is good evidence that this is true not merely of the body but also of the mind and society of man. The fundamental principles in all kinds of evolution are similar and if mutations and new Mendelian combinations, but not fluctuations, are the materials of physical evolution, and natural selection is the builder, it is altogether probable that the same is true of intellectual and social evolution.

Mutations and Their Causes. Regarding the causes of mutations we know very little, but it seems logically necessary to assume that these causes are both intrinsic in the germ-plasm and extrinsic in the environment; or, in the language of Darwin, "Although every variation is either directly or indirectly caused by some change in the surrounding conditions, we must never forget that the nature of the organization acted upon essentially governs the results." The same outer conditions acting upon different species or individuals produce different results and the possibilities of evolution are always limited by the organization of the germ-plasm. Some conceivable mutations do not and cannot appear because of these limitations. "Whales never produce feathers, nor birds whalebone," said Huxley; and probably no one ever really saw a green horse or a purple cow. But, although mutations cannot take place in all conceivable directions, there is no justification, in recent experimental work, for extreme views of orthogenesis which regard mutations as taking place in only a single direction. Furthermore, an extensive study of mutations shows that they are as frequently injurious as beneficial; indeed they are rarely as well fitted for existence as the stock from which they come.

It is highly probable that mutations take place in response to changes in environment, but it is necessary to remember that the environment of the germ-plasm is not merely the outer world but also the inner environment of the body organs and fluids and cells, and the innermost environment of the cytoplasmic and nuclear substances which surround the inheritance factors or genes.

Inheritance of Acquired Characters. But in spite of the fact that mutations probably occur in response to changes in the inner or outer environment, it is practically certain that specific fluctuations of developed organisms are not transmitted to the germ cells so as to reappear in the next generation. In short, there is no inheritance of specific characters acquired by the soma. Evolutionary changes do not first occur in developed organisms and then by some mysterious process get into the germ-plasm, but evolution consists in an evolution of germ-plasm which then manifests itself in the developed organism.

It is known as a matter of fact that acquired somatic characters are not usually, if ever, inherited. Environment, training, education, may greatly modify glands, muscles, nerves, and brains, but they do not change the germ-plasm *so as to produce these identical modifications in the next generation.* In a few instances it seems probable that chemical substances in the bodies of parents, such as hormones, or anti-bodies, may influence the germ cells or developing embryos so as to produce bodily changes in offspring similar to those in the parents, but in general it may be said that there is no satisfactory evidence that the specific modifications of development, due to particular conditions of life, enter into the germ-plasm and appear again in the next generation, in the absence of the environment which first called them forth. In short, the effects on development of environment, training, and education are not inherited through the germ cells and the hope of permanently improving the human race, or any other species, in this manner can only lead to disappointment and failure.

Social Inheritance. At the same time it must be remembered that man transmits to his descendants not only a particular germ-plasm which determines bodily qualities and mental capacities, but he also hands down through language, education, and customs, his own acquirements, experiences, and possessions as well as those of former generations. This has been called "social inheritance" to distinguish it from "germinal inheritance"; it is inheritance in the legal rather than in the biological sense. In this sense we have inherited from our ancestors language, literature, science, property, customs, institutions. These are no part of our germ-plasm, nor even of our blood and brain, but rather of our environment. Because of this social inheritance society may advance from age to age, each generation starting where the preceding one ended, as in a relay race,—whereas in our germinal inheritance each generation begins where the previous one began, namely from an egg cell, and the whole course of development must be repeated in each generation. Civilization is the result of the accumulations of social inheritance, and the future progress of society must depend largely upon this capacity of profiting by the experiences of former generations. (See Chap. X.)

Natural Selection. If mutations are the materials, natural selection is the architect and director of evolution, for although it does not originate fitness it continually eliminates the unfit and in the long run preserves only the fit. In certain quarters it has been fashionable of late to decry the importance of natural selection, but more and more, biologists are coming to recognize that it is the most important directing and perfecting factor in evolution.

Natural selection in its widest meaning involves not merely the overproduction of individuals and the consequent struggle for existence with elimination of the unfit, as Darwin formulated it, but it also includes the overproduction of many vital activities, such as motions and reactions, with the elimination of the unfit, as in the process known as "trial and error." Thus useful behavior is the residue left after useless responses are eliminated, and it is not necessary to hold with Darwin that fitness is always the result of the elimination of unfit *persons.* It is often the result of the elimination of unfit *reactions.* In short, natural selection is not only personal but also intra-personal.

Furthermore there are many kinds of fitness not only for different environments but also for different organisms and lines of evolution. Physical, intellectual, and social fitness are very different things, and it is possible to have any one of these without the other two. The past evolution of the human race has been guided by the elimination of the unfit, whether physical, intellectual, or social, and the future progress of the race must depend on this same process.

The Paths of Progress. Even a cursory study of the living world would justify the opinion that evolution has proceeded in all possible directions; crab-like it moves forward, backward, and sidewise. This is especially true of the minor stages of evolution represented by mutations, for these apparently occur in all directions without reference to their utility or inutility; however, in order to survive and become established, a mutation must run the gauntlet of natural selection and injurious mutations are eliminated. Much more is this true of species and larger groups which have had a longer and more severe trial than mutations and are consequently peculiarly adapted to their environments. In particular instances simplification and degeneration have occurred but in the main evolution has been progressive, that is, it is marked by increasing complexity of structures, functions, and adaptations, just as development from the egg to the adult is generally progressive, though in some instances and stages it is retrogressive. Particularly when one surveys the whole course of phylogeny or ontogeny it is evident that there has been progress from relative simplicity to complexity.

Definition of Progress. The very word "progress" calls forth a reaction from some people not unlike their response during the war to the word *Kultur.* A few persons seem to deny the existence of any such thing as progress, while others insist that it is too indefinite to admit of any formulation. Undoubtedly progress may occur in many different directions and toward different goals, but everywhere and always in the living world, it has certain fundamental characteristics. As is generally true in complex phenomena it is best defined in terms of causes rather than of results.

Everywhere in the living world, progress is brought about by increasing specialization and coöperation, or, in the language of biology, by increasing differentiation and integration. Whether it be the development of an egg into an adult, the evolution of primitive animals and plants into their more complex descendants, or the development and evolution of the body, mind, and society of man, progress everywhere is caused by increasing specialization and coöperation. In the development of an egg, which is the symbol and epitome of all progress, there is segregation of different structures and functions in different cells and parts of the body, that is, there is morphological division of substance and physiological division of labor, and at the same time there is increasing perfection of functions and adaptations. In the evolution of limbs or eyes or brains there is a similar increase in the complexity of differentiation and integration. In both the ontogenetic and the phylogenetic development of intellect and of society, there is increasing complexity and perfection of function and adaptation. All kinds of progress, whether of body, mind, society, art, industry, or science, are marked by increasing specialization and coöperation. As thus defined, progress may lead in different directions to very different ends, as is shown in the various types of locomotion, offense and defense, sense organs, nervous systems, etc., found in the animal kingdom. In man it has led to increased cranial and intellectual capacity, increased control over environment and greater freedom, increased size and complexity of social units, etc. But progress in each of these many paths is caused by increasing complexity and perfection of specialization and coöperation.

Limits of Progress. Biological progress, however, always has its limits; sooner or later differentiation reaches a stage beyond which it cannot go without destroying the internal balance, or integration, and the adaptability to external conditions. Furthermore, in the higher types of organization the mutual dependence of parts becomes so great that when one of these is injured or breaks down it carries with it to destruction the entire organism. As Professor Minot used to say, "Death is the price we pay for our differentiation." Germ cells and embryonic cells are potentially immortal; even tissue cells may be kept alive indefinitely when they are separated from the rest of the body, but the more complex the total organism is the more certain is its ultimate death.

The record of the rocks is full of instances in which groups of organisms have progressed to greater and greater complexity and have then become extinct. The roads of progress are strewn with the remains of creatures fearfully and wonderfully specialized, but which were unable to preserve internal balance or to adapt themselves to new environments and which therefore perished. Indeed, in practically every instance the road of ever increasing progress ends in extinction. But just as in the succession of generations highly differentiated cells and individuals die and new generations arise from relatively undifferentiated eggs, so when highly differentiated species become extinct new lines of progress start from generalized rather than from highly specialized types.

It is of course conceivable that differentiation might go on indefinitely in any line, the elephant might get a longer trunk, the giraffe a longer neck, and man a larger and larger brain, but while such things are conceivable they are not practicable for the reasons named. In any line of evolution progress is most rapid at first and then it gradually slows down until it stops, and in every well-tried path of evolution, progress has practically come to an end; further progress, if it occurs, must be in new lines and from relatively undifferentiated stock.

Progressive Evolution of Man. There have been three main lines of human evolution,—physical, intellectual, social,—

and it is generally assumed that in each of these lines we may look forward to endless progress. The infinite perfectability of man is a fundamental article of faith with many people, and yet all biological evidence indicates that it is not supported by fact. Not only the history of other organisms but also that of man himself indicates that progress in any particular line is limited.

In bodily evolution man has made no very marked progress during the last twenty thousand years at least. Undoubtedly there have been minor changes in the human body, probably an increasing resistance to certain diseases due to the elimination of those persons who were more susceptible, as well as certain degenerative changes in sense organs, hair, teeth, and toes; but such changes are insignificant when compared with those which marked the transition from pre-human ancestors to man, or even those changes which brought about the differentiation of the primary races of mankind. The physical evolution of man has slowed down almost to a standstill, and if it is to go forward again it will probably be in new lines and in response to new and very different environmental conditions.

The opinion is widely held that intellectual evolution is advancing rapidly and in justification of this belief is instanced our increasing knowledge of the world and of man. But it is necessary to distinguish between intellect and knowledge, between the capacity for knowing and things known. Undoubtedly we know many more things than the ancients or even than our own parents, but has there been any increase in intellect comparable with the increase in knowledge which has marked the last few centuries? On the contrary, those who have devoted much attention to this subject are of the opinion that no modern race is intellectually equal to the ancient Greek race. Not only did this race produce a larger number of illustrious men than has any other race during an equal period of time but the general intelligence of the citizens was probably higher than in any modern nation.

Undoubtedly popular education brings to light many persons of marked intellectual capacity who in former years might have remained "mute, inglorious Miltons"; there are many more opportunities to-day for discovering the inherited capacities of men than there were in ancient times, but anyone who thinks that intellectual capacity is undergoing rapid evolution needs to consider seriously the widespread emotionalism, irrationalism, and superstition of this twentieth century of enlightenment as compared with the golden age of Greece in the fourth or fifth century B. C. Indeed, since the times of the Crô-Magnon race, probably twenty thousand years ago, there has been no marked increase in man's cranial capacity, and probably little or no increase in his inherent intellectual ability. There are better opportunities to-day than ever before for the development of the individual but the intellectual evolution of the race, no less than the physical, has slowed down until it has practically stopped.

In human society, however, tremendous changes are taking place and many of these are in the direction of progress. The great advances in our knowledge of and control over nature, which are such a distinctive feature of our present civilization, are the results of coöperative effort. The developments of science, literature, and art, of agriculture, industry, and commerce, of education, government, and religion, are the products of increased specialization and coöperation of society. The fact that social change is going on so much more rapidly than either physical or mental evolution is due to the fact that past experiences and acquired characters are handed down through "social inheritance," but not through the germ-plasm. If we consider those social changes only which are due to modifications of the germ-plasm, such as inherited instincts and capacities, we find that evolution is probably no more rapid in society than in the case of the body or mind of man. Within historic times the social instincts of men have not changed more fundamentally than their intellectual capacities or their germ-plasm.

Unlike any other form of evolution, the rapid changes which are taking place in human society are not due to changes in germ-plasm, nor even to changes in the developed individual, but merely to changes in environment. They are not even skin-deep, they are only clothes-deep. It may be questioned whether these changes are really evolutionary at all since they do not involve changes in germinal inheritance, intellectual capacity, or social instincts, but are merely the accumulation of experiences from generation to generation, as an individual accumulates knowledge from year to year. Indeed, the progress of human society is much more like the development of an individual than it is like the evolution of a species.

But whether we regard social development as a form of phylogeny or of ontogeny, as a result of inheritance or of environment, we cannot fail to see that it is going forward at a rapid rate and that it is fraught with the most stupendous possibilities for the future. The only great progress which the human race has made during the past twenty thousand years has been social, and so far as we can now see into the future the progressive evolution of mankind must depend to a great extent upon society. It is particularly in the field of discovery and invention that progress has been most notable. Nothing could more strikingly illustrate this than the comparison of the state of the world one hundred years ago with that of to-day. Whole regions of the universe have been explored, the very existence of which was not dreamed of a generation ago. Inventions which would seem incredible or magical were they not so common are everyday conveniences. Diseases and epidemics which were once regarded as the direct acts of an inscrutable Providence or of unscrupulous demons are now prevented or controlled. All this notable progress in the conquest of nature is the result of coöperative effort. No one person, however great his contributions, could have made any important advance alone and unaided. Every discovery is based upon many others which have gone before, and all civilized countries and ages have contributed to the advancement of knowledge. In short, progress during historic times has not been in the individual but in the association of individuals, not in the inherited capacities of persons but in the organization of society.

Not only the direction of social evolution, but also the future evolution of the body and mind of man will be determined to a great extent by society. Progress through natural selection is exceedingly slow and wasteful, intelligence is a great time-saver as contrasted with "trial and error," and intelligent artificial selection affords the most rapid and satisfactory means for the improvement of the human race. There is no doubt that mankind could, if it would, breed a more healthy, more intelligent, more moral type than the general average of the existing race. By means of artificial selection, requiring no more intelligence than that which is now used in the breeding of domestic animals, weakness of body, of mind, and of social instincts could be largely eliminated, and the average of the race could be raised to a level more nearly that of the best existing individuals. To a large extent mankind will determine its own destiny on this planet. Whether it has wit enough to save itself from the dangers which now threaten is a serious question.

Present Conditions and Tendencies

Our watchers on Olympus would see in present conditions and tendencies of the human race some promising prospects but much cause for grave concern. Perhaps the conditions which would cause most anxiety are the nullification or complete reversal by man of some of the most important principles which have guided evolution in the past. For the first time in the history of life upon the earth, a single species now has the power of controlling to a large extent its own evolution, and it has begun by radically changing some of the conditions of progress which have prevailed hitherto. A large part of the human race is now engaged in the most stupendous and dangerous experimentation upon itself; without any adequate knowledge of the mechanism of evolution it has begun to tinker with that mechanism, throwing certain parts out of gear, destroying others, and in general paying little or no attention to the results.

Decreasing Influence of Natural Selection. In spite of some notable exceptions, the leading biologists of the world agree that natural selection has been the most important guiding and perfecting principle in past evolution, and on the whole it has made for progress. At every step in the past course of evolution it has sifted the unfit from the fit, and while it has not originated fitness, it has preserved it, and in general it has directed evolution into paths of progress by closing up other paths. Those whose only conception of natural selection is that of a life and death struggle between individuals of the same species may well rejoice that mankind is to a certain extent freed from this struggle, and that in human society coöperation is becoming a more important means of progress than competition. But natural selection in its widest sense means the elimination of the unfit, whether these are reactions, instincts, customs, persons, races, or species; and if in human society coöperation is more beneficial than competition, cooperation rather than competition will be favored by natural selection. And in similar manner if intelligence is more beneficial than brute strength or cunning or instinct, intelligence will be favored. In short, there are many kinds of fitness in different lines, and in the case of man, if natural selection were not interfered with, it would lead to the partial or complete elimination not only of the physically unfit but also of those who are mentally and socially unfit.

Of course man cannot wholly eradicate natural selection from human life; the most monstrous forms cannot possibly be saved and the more abnormal they are the earlier they die; the seriously defective rarely come to maturity or are capable of reproduction and even those that survive and reproduce are usually handicapped at every stage. Natural selection remains and will probably ever remain an important factor in human evolution, but just as far as is possible it is being minimized or set aside in civilized states. In the finest fervor of altruism and with the most extraordinary expenditure of money and effort civilized society manages to save many of those who are feeble in mind and body as well as criminals and enemies of society. And no doubt much of good is gained in this way, for not only are great minds and souls sometimes lodged in frail bodies but it is probably more valuable to the race to preserve a spirit of altruism and social justice than it is to rid society of its degenerates by ruthless methods. Nevertheless, neither justice nor altruism requires that such persons be permitted to propagate their kind; lasting progress cannot be based upon a one-sided development of body or mind; ideally, as well as biologically, life and progress are balanced as it were between many different forces, principles, and ends, and neither physical, intellectual, nor social developments should go so far as to destroy either of the others.

Galton says, "Our human stock is far more weakly through congenital imperfection than that of any other species of animals, whether wild or domestic." It cannot be doubted that this greater weakness and imperfection is due to failure to eliminate the unfit, but there is no clear evidence as to whether congenital physical degeneracy is increasing or decreasing at the present time. Athletics, physical education, medicine, and sanitation have made great advances in recent years and this has had a beneficial influence on the health and vigor of this generation, but there is no satisfactory evidence that these effects are inherited. The average length of life has been increased, chiefly by saving the babies, but the maximum length of life has not been raised; men live no longer now than in the time of Methuselah, and since longevity is hereditary, it may well be that the artificial prolongation of the lives of those who are hereditarily weak and short-lived may actually reduce the natural longevity of the race as a whole.

Mental and moral degeneracy runs in families, as is proved by such cases as the "Jukes," "Kalikaks," "Zeros," "Nams," "Ishmaels," etc., but social selection against such groups is pretty severe and it does not seem probable that extreme defectives of this class are increasing very rapidly. Inmates of custodial institutions are usually prevented from having offspring and they do not greatly threaten racial standards; the greatest danger comes from somewhat less defective individuals who are at large and are free to have as many children as they can.

Retrogressive Selection of Civilization. Much worse than this partial failure of natural selection is the retrogressive selection of civilization. If society had deliberately set about the propagation of the unfit it could hardly have devised more effective means than many of those which are now in vogue. Frequent wars have taken the best blood of the nations, and while casualties in modern battle are more or less indiscriminate, soldiers represent a selected group; those who go to war are usually the young, the strong, the capable, while the weak, incompetent, and degenerate are left behind as unfit for military service. Furthermore, these casualties must be doubled when their influence on the race is considered, for in general every man killed leaves one woman unmated for life. As a result of the last war millions of women can never marry or have children. Among these are some of the best human stock the world possesses,—and thus the race is made poorer for many generations to come. Enforced celibacy in many religious orders and societies of scholars has led to the extinction of some of the world's most gifted lines. The present customs of mate selection condemn many of the finest women in the world to spinsterhood, while the feather-brained and sexually-daring "flappers" readily find mates. On the other hand, personal ambition and selfishness, the prevalence of prostitution and illicit sexual relations, the fear of misalliances, divorce, and alimony are potent causes of bachelorhood. In both cases the results are that many of the best human lines are wiped out. Galton has shown that on the average people who marry at twenty-two will leave twice as many descendants at the end of a century as those who marry at thirty-three and in a few generations they will actually possess the earth. And yet the increasing time required for education, as well as more luxurious standards of living, have made early marriages almost impossible among professional and business classes, with whom the most vigorous and fertile years of the reproductive period are years of sterility. Finally, luxury, soft living, and selfishness have made children unwelcome among many married people who have shown qualities of success in life and whose hereditary traits are above the average. Under such conditions the general average of intelligence and social fitness in the race as a whole must inevitably decline.

There is an evident tendency to assortative mating in modern society due not merely to similarity of social status and ideals but also to the more potent factor of propinquity. Generally men and women representing the extremes of the social or intellectual scale do not marry and it has been claimed that owing to this fact there is a constant tendency for society to be split up into hereditary classes. Some authors maintain that the more intelligent and the less intelligent elements of society are separating more and more widely, that the successful are being split off from the unsuccessful, and that, in general, human society is differentiating into hereditary classes owing to the tendency of like to mate with like. However, when one considers the world as a whole, rather than a few small social groups, it is plain that any such tendency to form hereditary classes is more than overbalanced by other factors. The permanent stratification of society is prevented by the rising of genius from the lower levels and the sinking of mediocrity from the higher, by the boiling of the social melting pot, by new mutations and Mendelian combinations, all of which contribute to cast down the mighty from their seats and to exalt those of low degree. In the past history of mankind there have been many attempts to establish hereditary classes; where now are the castes of rulers and slaves, statesmen and soldiers, scholars and priests, craftsmen and farmers, of ancient Egypt, Assyria, Greece, and Rome, or even of medieval Europe? The ideals of the race as a whole are against the establishment of such hereditary classes and in favor of democratic equality of opportunity, with social position dependent upon individual merit rather than upon family name or class privilege, and these ideals are probably sound both socially and biologically.

Some advocates of eugenics have dreamed of the establishment of an intellectual aristocracy by the segregation and intermarriage of the most highly gifted members of society, such as the prize scholars in colleges and universities. No doubt this could be accomplished if some power could bring about such segregation and propagation, but unless these prize scholars combined many excellent physical and social qualities as well as mental ones such segregation would probably lead to very unsatisfactory results. It would seem to be better for prize scholars to marry prize athletes and thus preserve the general all-round excellence of the race, rather than to attempt to develop an intellectual or social aristocracy.

Decreasing Birth-rate of Intellectual Classes. There is no doubt that intellectual ability is an inherited trait, in spite of the fact that great men have sometimes come from unknown ancestors and unknown men from great ancestors. Mental capacity probably depends upon a number of inheritance factors, and occasionally each of two mediocre parents may supply factors which the other lacks, thus giving rise to an excellent combination which is the initial step in the production of a great man; on the other hand, even superior parents may sometimes furnish a bad combination of inheritance factors, and the resulting child may be mediocre or inferior. But Galton has shown that in an equal number of distinguished and undistinguished families there are about five hundred times as many chances that a distinguished man will come from the former as from the latter. No doubt environment is an important factor in the development of intellect but the possibilities of such development are marked out in the germ-plasm. Superior intellectual ability is inherited no less than inferior ability, genius no less than feeble-mindedness.

It is therefore most important for the intellectual progress of the race that the more intelligent classes should increase and multiply and that the less intelligent should be relatively less fertile,—and yet the reverse of this is true. In spite of individual exceptions, the graduates of our colleges and universities probably represent on the whole the most intelligent portion of our population; they have been sifted out from their less gifted fellows by the grammar schools, high schools, and colleges, until, on the average, they are a very highly selected group. But this group is not perpetuating itself. The average number of children per graduate of Harvard and Yale for the years 1881-1890 was about 1.5. Up to the year 1901 the average per graduate of Vassar and Bryn Mawr was about

.8, of Mt. Holyoke about .7, and of Smith College a little less than .6. In other words, as Cattell says, the average graduate of Harvard or Yale is the father of three-fourths of a son and the average graduate of the women's colleges named is the mother of rather less than one half of a daughter. The birth-rate among the members of the honor society, Phi Beta Kappa, is much lower than that of the average graduates, and in general it may be said that the higher the intellectual attainments, the lower is the average birth-rate. This is true not only of college graduates but of the more intelligent people generally. Among American men of science, Cattell finds that the birth-rate has decreased in a single generation from 4.66 per family to 2.22. Since in the general population it takes an average of three or more children per family to preserve present numbers, it will be seen that these highly selected lines are dying out. And as rapidly as others of superior intelligence rise out of the general population they also become relatively infertile. Thus the intellectual cream of the race is continually skimmed off, and it is a question how long it will continue to rise.

There is great enthusiasm to-day among certain people, who are generally childless, for small families; the race is to be regenerated by birth control. But this "reform" begins among those who, because of good hereditary traits, should have large families. If only those who should not have children were to practice birth control, it would be a blessing to mankind, but there can be no doubt that thus far it has greatly reduced the number of children among the intelligent and prudent classes, without influencing to any extent the birth-rate among the unintelligent and imprudent. Whether this result will be reversed in the future no one can predict. Alexander Graham Bell believes that it will, in time, benefit the race by eliminating those among the intelligent classes who are lacking in parental instincts. Irving Fisher says there are three possibilities in birth control: (1) it may cause depopulation and, ultimately, extinction of the human race; (2) it may reduce the reproduction of the prudent, intelligent, and ambitious, leaving the imprudent and unintelligent; (3) it may cut off the strain of the silly and selfish, the weak and inefficient. There is little if any likelihood that the first of these possibilities will ever be realized; depopulation may result in certain countries but it will never become universal through birth control. The second possibility is already an actuality so far as the reduction of the birth-rate among the most progressive people is concerned. It does not seem probable that the third possibility can greatly benefit the race before much damage has been done by the second. Of course if those who preach and practice birth control are, when measured by the highest standards, silly, selfish, weak, or inefficient to a greater degree than others, then, and then only, is it working for the betterment of the race. It seems incredible that people of good hereditary traits should think that they can improve the human breed by committing racial suicide. "There be those which have made themselves eunuchs for the kingdom of heaven's sake," but when before in the history of the world have sane men made themselves eunuchs in order to win the kingdom of the earth? Those feminists who declare that they would rather die than have children have made their choice between the only alternatives possible,—death to their lines and to their participation in the future of the race, or children.

But while the more progressive lines are, as a whole, dying out, the general population of this country and of the world is more than maintaining itself, and the less intelligent, independent, and aggressive portions of the population are probably increasing most rapidly of all. Thus the Scriptures are being fulfilled that "the meek shall inherit the earth." It is often said that a high birth-rate among the lower classes is always offset by a high death-rate, but in civilized society this is by no means the case.

In a recent paper of great interest and importance, Pearl has shown that the "vital index," that is, the ratio of births to deaths within a given time, differs greatly in different elements of our population; it is lowest among the old American stock, and highest among the foreign-born population. In New England and in New York State, the native population of native-born parents produces only about .8 or .9 of a birth for each death, while in the country at large "the native population produces only a fraction over one baby for each death. In other words, the native population . . . is in about the same state as France before the war, and not in as vigorous a state as the French population is now." As contrasted with this, he says, "Generally speaking, the foreign population produces in this country approximately two babies for every death."

In so far as this foreign population is equal in quality to the native stock which it is replacing there is no cause for alarm in this, and except for sentimental regrets on the part of the old American stock, it may be welcomed as a rejuvenating factor, but if this foreign stock is in the main inferior in quality to that which it is replacing, then indeed is there cause for concern.

Race Differentiation vs. Race Amalgamation. Another important principle in past evolution which is being reversed in the case of man is that of racial isolation and differentiation. Since all types of mankind interbreed freely, it is evident that distinct races could not have been established and perpetuated except by the aid of isolation, chiefly geographical. On the whole, race differentiation has made for progress; it has led to the establishment of races peculiarly fitted to the environments in which they are found and it has favored the establishment of types superior in certain directions though they may be inferior in others.

However, with increasing means of communication, and as a result of migration and commercial relations, there is no longer complete geographical isolation of any people and the various races of mankind are being brought into closer and ever closer contact. Man is now engaged in undoing the work of hundreds of centuries; if in the beginning God "made of one blood all nations of men," it is evident that man is now making of all nations one blood. In the United States practically all the races of mankind are represented and a study of the census returns shows that all the European races in this country are being rapidly fused together. Pearl has recently shown that from "one fourth to one half as many children are produced in a given year from mixed matings (in which one partner is American) as from strictly American-born persons. Amalgamation of the immigrant elements into the previously existing complex is certainly going on apace."

The "typical American" is the product of the fusion of various European races and we, at least, believe that the results of such race mixtures are good. Even European races are rarely if ever pure, but represent mixtures of many different stocks. If "pure" English, Irish, Scotch, Dutch, German, Russian, French, Spanish, or Italian lines are traced back only a few generations they are found to include many foreign strains. The author of *Robinson Crusoe* wrote two centuries ago of the "True-born Englishman":

> These are the heroes that despise the Dutch,
> And rail at new-come foreigners so much;
> Forgetting that themselves are all derived
> From the most scoundrel race that ever lived;
> A horrid crowd of rambling thieves and drones
> Who ransacked kingdoms, and dispeopled towns;
> The Pict, and painted Briton, treach'rous Scot,
> By hunger, theft, and rapine, hither brought;

Norwegian pirates, buccaneering Danes,
Whose red-haired offspring everywhere remains;
Who, join'd with Norman French, compound the breed
From whence your "true-born Englishmen" proceed.

Even the primary races of mankind are rapidly fusing in many parts of the world. In the United States from 15 to 20 per cent of the total negro population of about 10,500,000 are mulattoes and these are increasing more rapidly than the pure blacks. In South American countries it has been estimated that there are about 26,000,000 whites, Indians, and negroes, and about 20,000,000 of mixed blood. In Australia and New Zealand, after only a little more than a century of contact with the whites, there are about as many "half castes" as full-blooded aborigines. Similar tendencies to amalgamation of the primary races are found in Mexico, the West Indies, Africa, Indo-China, the islands of the Pacific, and in other parts of the world. It is said that there are no cases in history where two races, however different, have for long occupied the same territory and yet have preserved their racial purity. Even the Jews, who are a peculiarly separate and distinct race, have received large admixtures of Gentile blood in every country in which they have lived. Fishberg says that in western Europe, America, and Australia from 25 to 50 per cent of all Jews who marry, marry non-Jews.

If this movement goes on, as we have every reason to expect that it will, it can only end in the more or less complete fusion of existing races, and it needs only the vision that can look ahead a few thousand years at most to see all races blended into a common stream. What the results of such fusion may be we can only guess, though its effects in ancient Egypt, Greece, Italy, and more recently in various countries of eastern Europe, the West Indies, Mexico, and South America are by no means reassuring. Hybrids are not necessarily inferior, and they are sometimes superior to either of the parent races. Mendelian inheritance holds good in the crossing of human races as well as everywhere else and it leads to all kinds of combinations of the qualities of the parents. Accordingly some hybrids may be expected to show the bad qualities of both parent races while others show the good qualities of both, but it is practically certain that the general or average result of the crossing of a better and a poorer race is to strike a balance somewhere between the two.

If only good ore goes into the "melting pot" there is no cause to fear for the result; and if those hybrids which combine the good qualities of the parent races could be segregated and bred, a race superior to any existing human type could probably be established. This is just the method followed by breeders in the production of improved races of plants and animals, many of which are the products of deliberate hybridization. But the breeder ruthlessly eliminates inferior stock and breeds only from the best, and if by some similar process it were possible to eliminate from reproduction the inferior racial combinations and to perpetuate the best, we might expect to get from this great experiment in human hybridization a very superior breed of men combining the good qualities of all the constituent races. It seems very doubtful whether any such result as this will ever be attained, and in the absence of such selection and segregation the general result of race amalgamation must be an averaging of the qualities of the parent races.

The character of a composite race will depend not only upon the qualities but also upon the relative numbers of the races which enter into it, and the latter will depend upon the present numbers of existing races, their rate of increase, cultural development, and the habitable portions of the globe which they control. In all of these respects the white races hold the lead, followed in turn by the yellow, the brown, the black, and the red races, and it is evident that unless the white races destroy one another, commit race suicide, or die at the top, they are destined to furnish the principal contribution to the future population of the globe.

The Limits of Population. Finally, the human population of the world is rapidly approaching its maximum—for while populations tend to increase continually the limits of the habitable globe remain fixed and the means of subsistence are subject to the law of diminishing returns. Pearl estimates that within 200 years the population of the United States will have reached its maximum of about 200,000,000. Alfred Marshall calculates that the population of the entire world will have reached its maximum of about 6,000,000,000 in 200 years. These estimates assume that increase of population and of means of subsistence will in the future conform to the same mathematical formulæ as hitherto,—an assumption that is probably justified. If these estimates are correct the grandchildren or great-grandchildren of persons now living may see the maximum population of this country, and perhaps of the world, attained. Even if by means of greatly improved agriculture or by revolutionary scientific discoveries this time should be doubled it would still be a relatively short period before the limits of the possible population of the globe would be reached. Thereafter the population will remain stationary, either through increase of the death-rate or decrease of the birth-rate. Under these conditions it is probable that both natural and artificial selection will be intensified. It is reasonable to expect that on the whole natural selection will make for progress and it does not seem probable that artificial means of limiting population will continue to cut off the better stocks and to favor the worse.

There is ground to hope, therefore, that in a crowded globe both natural and artificial selection will make for the improvement of the race, but such improvement is likely to be slow and painful. Natural selection, under various aspects, is still the most potent factor in directing evolution though it is extremely slow in its action and excessively wasteful. There is reason to hope that in the near future intelligent human selection may coöperate with natural selection, thus rendering progress more rapid and more merciful. Certainly eugenical education should begin to bear fruit,—that is, more children of the better sort and fewer of the worse variety,—within the next generation. Unless it does we may be sure that the time will come when in a crowded globe natural selection will reassert itself and there will be a return to "nature's simple plan" of promoting fitness by the ruthless elimination of the unfit.

The Immediate and the Distant Future

The Immediate Future. In the midst of all these conditions and tendencies of the human race,—the decreasing influence of natural selection, the retrogressive selection of civilization, the decreasing birth-rate of the more intelligent classes, the increasing amalgamation of races, the rapid approach of the time when the earth will be fully populated and its natural resources exhausted or greatly diminished,—in the whirl of all these changes it does not seem probable that human evolution will long remain stationary. On the whole, it must be admitted that these tendencies do not point to racial progress, and some of them presage retrogression, degeneration, and decay unless they can be overcome.

There is much in the modern world that reminds one of the period of decline of former civilizations, and especially of Greece and Rome, and many persons have wondered whether our civilization is not traveling the downward road to a similar end. In both Greece and Rome the decline was preceded by a large amount of race mixture, and a decreasing birth-rate among the higher classes, while it remained relatively unchanged elsewhere. Momsen says that the decay of Rome was due mainly to "the difference between the fertility of the higher and the poorer classes." Tenny Frank[2] concludes that in Nero's day, about 90 per cent of the plebeians on the streets of Rome had oriental blood, while the whole Empire was a "melting pot" in which the oriental was a large part of the ore:

> Race suicide curtailed the stock of the more sophisticated, the aristocracy, and the rich. Before our day, only at Greece and Rome was reproduction under rational control and there the race went under. Of forty-five patricians in Cæsar's day only one is represented by posterity when Hadrian came to power. Of the families of nearly four hundred senators recorded in 65 A. D. under Nero, all trace of a half is lost by Nerva's day, a generation later. The voluntary choice of childlessness accounts largely for the unparalleled condition—and is probably the most important phase of the whole question of the change of race.

A striking parallel to what is found in most of the civilized world to-day! Whatever may have been the causes of the decline of former civilizations, it is plain that there were left in other parts of the world strong human reserves that could carry forward the standard of civilization which was dropped by a dying race. But in a world where practically all western nations are suffering from this sickness of civilization, and in which racial amalgamation is fusing all into a common type, where are the reserves that can be rallied to the standard, if civilization should again decay? If history should repeat itself and the western nations should go down as did Greece and Rome, possibly Russia, or China, or Japan might take up the banner and civilization once more begin its westward march around the world.

But there is this important difference between present conditions and those of any former age,—our knowledge of and control over nature are vastly greater than ever before and the means of increasing and diffusing knowledge were never so good as at present. If knowledge and education can save the race the prospect is promising, for they were never before so widespread; the possibilities of continued progress rest on education, eugenics, and enlightened effort.

---

[2] *American Historical Review,* Vol. 21, 1916.

Man himself is no longer the mysterious being, unknown and unknowable, that he was once considered. He also is a part of nature and in body, mind and soul is subject to natural laws. Diseases of the soul or of the mind are no more the result of demoniacal possession than are diseases of the body. The ills of society are the results of natural causes and can be remedied only by controlling those causes. The conquest of the inanimate forces of nature is a great adventure, but the scientific understanding and control of the ills of man and of society is the greatest adventure upon which any adventurer ever embarked. The growth of the spirit of scientific inquiry and its extension to man and all of his affairs is one of the most hopeful signs of this age.

Education is the first and most important step in combating these tendencies to racial decline. Assuming that the social instincts of the major portion of mankind are sound and that there is sufficient intelligence in the race at large to recognize the dangers that threaten, it ought to be possible by education to meet these dangers and overcome them. A more thorough and widespread knowledge of the nature of man and of the principles of heredity and development would lead to the elimination of many of these dangers, for in the main we have sinned through ignorance. Such knowledge would prevent the importation and propagation of physical, mental, and moral degenerates; it could prevent the amalgamation of better races and families with poorer ones; it should increase the number of good matings and of superior children; and it should make human life healthier, happier, more rational, and more efficient. Whatever good may come to the race through better legislation, sanitation, eugenics, or euthenics will be made possible by better education.

What part eugenics may play in the betterment of the human race cannot now be foreseen. There is no doubt that, by means of a thoroughgoing system of eugenics, feebleness of body and of mind could be largely reduced and the race as a whole made more healthful and intelligent; in short, the general average of the race could be raised more nearly to the level of the most perfect men and women of the past or present. It is doubtful whether eugenics can go farther than this and there is no probability that it can ever produce a race of supermen. Important as eugenics is in preventing racial degeneration it does not hold forth the hope of endless human progress. For the present at least the most that it can do is to take the place of natural selection in limiting the propagation of the feeble-bodied and the feeble-minded and in favoring that of the strong and sane. This would at once preserve and perpetuate the best human lines and would in time raise the average of the race as a whole but probably it would not produce a new and better species of man. The eugenicist can neither produce new mutations nor does he know what mutations or new combinations of characters will be most useful and most viable in future ages. If the fads and fancies of reformers could be established in the germ-plasm and all men could be made eugenically equal the whole race might come to a rapid end. It is probably fortunate that men are not charged with the duty of directing future evolution, and we can only hope that nature, which has directed progressive evolution from amœba to man, without human guidance, may work still greater wonders in future ages.

But important as these things are, they are not enough. To be effective for lasting good, knowledge must rest upon character. Unless the instincts of service, sympathy, love prevail; unless the ideals of altruism, justice, and morality persist, neither education nor science can save our civilization. The whole future welfare of the human race rests upon these decent instincts and social ideals of mankind. Here are the foundations upon which civilization rests and, if they decay, the superstructure, however great and glorious, will fall to ruin.

Finally the lesson of past evolution teaches that there can be no progress of any kind without struggle; in physical evolution progress has come through the struggle for existence and for more abundant life; in intellectual evolution, through strivings for freedom and enlightenment; in social evolution, through the victory of social instincts and ideals over anti-social ones. The improvement of the human race, if not the further evolution of man will depend in part upon enlightened human effort. To us it is given to coöperate in this greatest work of all time and to have a part in the triumphs of future ages, not merely by improving the conditions of individual life and development and education, but much more by improving the ideals of society and by breeding a better race of men who will "mold things nearer to the heart's desire."

The Distant Future. What the distant future may hold in store for the human race we can only guess. It may be that the entire race will become extinct and leave the dominance of the earth to other living things. Although this has been the history of many dominant species in the past it does not seem probable that it will be the fate of man, for he is able to adapt himself to changed conditions, to modify his environment, and to control his destiny as no other creature that has ever lived on the earth has been able to do. If conditions of life should ever become so adverse that the entire human race should become extinct we may probably assume that all other higher animals would also perish.

It is possible that the entire race may suffer retrogressive evolution and return to a less highly organized condition. Many other types of animals have passed the climax of their evolution and have then declined and their degenerate representatives still survive. But in these cases other forms better fitted for survival have taken their places and progress has continued in other lines. Intellectual and social evolution has reached a climax in man and it has so greatly increased his control over himself and his environment that it seems scarcely possible that it will universally and permanently decline and be replaced by less adaptable and less efficient characters.

Perhaps in future ages the progressive evolution of man will continue, somewhere and somehow. If higher species of man evolve in the future it is not unlikely that this will occur, as in the past, in connection with great secular changes, over which man has no control, such as the rising and sinking of continents, the formation of deserts or mountains or oceans, or changes in climate comparable to the glacial and interglacial epochs, during which human evolution made such wonderful progress.

In the present conditions and tendencies of the human race, in the contest between progressive and retrogressive forces, we see much cause for anxious concern, but thinking on the distant past and the boundless future creates a feeling of detachment and of philosophic calm like that of the dwellers on Olympus. We cannot see clearly the next scene, we can scarcely imagine the next act, and the end of the great Drama of Evolution, if there is to be an end, is a matter of faith alone.

O, yet we trust that somehow good
Will be the final goal of ill,
To pangs of nature, sins of will,
Defects of doubt and taints of blood.

CHAPTER XIII

THE MECHANISM OF EVOLUTION

WESLEY R. COE

PROFESSOR OF BIOLOGY, YALE UNIVERSITY

The preceding chapters have demonstrated that civilized man, in common with all other forms of life, is the product of evolutionary processes which have been operative from the earliest times. In this concluding chapter a more detailed examination will be made of the physical mechanism by means of which these evolutionary changes take place. Evolution implies a changed heredity; organic evolution is, in fact, nothing more than the expression of the countless hereditary changes that have been registered in the living substance since those remote times when life first came into existence. The bodies of men or of animals or of plants may be profoundly altered during their lifetime without having the slightest effect on subsequent generations. And, on the contrary, the inheritance may be altered without affecting the body in which the change occurs. In the latter case the changed heredity may manifest itself in the offspring, possibly by some visible change in form or structure. But whether it reveals itself by a visible change or not the altered heredity is undoubtedly present and it will continue in existence in every individual to which it is transmitted in all subsequent generations. Only by the death of every one of the individuals to which it is transmitted or by some further change in the hereditary unit itself can the altered germplasm be eliminated from the racial stock in which it has made its appearance.

Such changes in the inheritance of an organism are termed mutations, and every one of the countless differences between the animals and plants which are living to-day represents a mutation which has occurred at some previous time. Evolution is thus nothing more than an accumulation of mutations which have been combined in those organisms reproducing sexually into the extreme complexity of hereditary units found in each individual of the various groups.

When mutation stops—if it ever does stop—evolution likewise comes to a standstill except for the constantly new combinations which may be formed by the shuffling and recombination of previous mutations in accordance with Mendel's laws of heredity.

But there is no evidence that mutation ever can stop. As stated in the preceding chapter, there seem to be periods in the evolutionary history of each species during which mutations succeed each other in rapid succession, to be followed by other periods when the species remains relatively stable. Most of these mutations, judging from those which are occurring at the present day, are of minor importance and are but slowly cumulative during successive generations, but from time to time appears one so profound as to influence even the survival of the individual which bears it.

The vast majority of mutations occurring today make no improvement in the adaptive characteristics of the species in which they take place; in fact it may be questioned if a single one has been observed in animal or plant breeding which would not prove actually detrimental to the species in its natural environment. But under the environment which man provides they are vastly superior to the ancestral stocks.

A few generations, or a thousand generations, form but a minute fraction of the life of a typical species and it may be unreasonable to expect a single hereditary improvement in that relatively brief interval, but it is not unthinkable that a type better fitted to its natural environment will arise sooner or later in even those which now appear to be most perfectly adapted.

Until the past few years very little was known as to the precise mechanism which nature has evolved for the transmission of the hereditary units, and even to-day the actual processes by which these units become altered when a mutation occurs are far from having been explained in terms of physics and chemistry. Much less is known about the causes for the changes which occur in nature, and although the physical apparatus for producing mutations may be found in many laboratories the experimenter has as yet no control in directing the types of the mutations which he produces.

It has been proved conclusively, however, that the hereditary mechanism, and consequently the mechanism of evolution, is resident in the chromosomes found in the nucleus of each of the cells which compose the body. Each chromosome contains a large number of hereditary units, called genes, the interaction of all the genes, under the control of environmental influences, being responsible for the development of all the characteristics which the individual will show during its entire lifetime.

Each of these countless genes is doubtless a living physicochemical entity which occupies a definite position in one of the chromosomes and divides into two parts whenever the chromosome reproduces itself by division. It is believed that the genes lie in linear arrangement on the chromosomes much like the beads on a necklace (Figures 77, 78).

In sexually reproduced organisms all the genes except those in the sex-determining chromosomes occur in pairs (allelomorphs), one member of each pair being derived from each parent. This results from the fact that in the process of maturation and fertilization of the egg from which the individual is derived one member of each pair of chromosomes in the egg is discarded, to be replaced by similar chromosomes brought into the egg by the spermatozoön. Thus each fertilized egg, and hence each cell of the body which develops from it, will have a definite number of pairs of chromosomes. One member of each pair is supplied by the egg and hence derived from the maternal parent, while the other member is furnished by the spermatozoön and represents the paternal inheritance.

In the fruit fly, *Drosophila,* for example, there are four pairs of these chromosomes in each cell, differing somewhat in size and appearance, as shown in figure 76. The two sexes are differentiated by the presence of a pair of sex-determining chromosomes, both members (xx) being similar in the female, while in the male one member (x) is of quite different appearance from its mate (y). In these four pairs of chromosomes all the hereditary units of the individual appear to be situated. Similarly all the genes in a human being are combined into twenty four pairs of chromosomes in each cell of the body, twenty four single chromosomes going to each egg cell or sperm cell. Each of the two parents thus supplies to the fertilized egg—which by its continued division produces all the cells of the child—an inheritance mechanism consisting mainly, if not exclusively, of twenty four microscopic chromo-

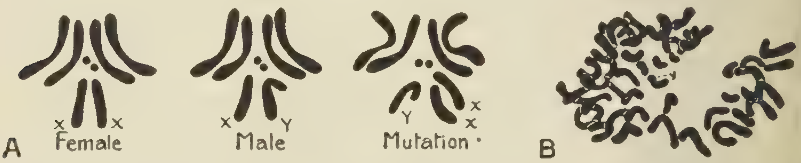


FIG. 76.—*A*, Diagram of the four pairs of chromosomes in a cell of the fruit fly, *Drosophila.* In the female the sex-determining chromosomes (xx) are similar, while in the male they are quite different in appearance (xy). By the process of non-disjunction a mutation may occur, producing a female with an additional x-chromosome, giving her a different chromosomal complex and thereby an altered heredity. (After Morgan.) *B*, The twenty four pairs of chromosomes in man. (After Painter.)

somes. It must be emphasized, however, that both egg cell and sperm cell contain within themselves a variety of cytoplasmic bodies absolutely essential not only to the development and differentiation of the cells which will later form the body of the child but also to the nutrition or maintenance of the hereditary units. But there is no satisfactory evidence that the cytoplasm contains entities of a strictly hereditary nature, that is, those which are not activated and controlled, either directly or indirectly, by the chromosomal genes, as will be explained more fully in a following paragraph.

Nevertheless it must be admitted that while all the experimental evidence points to these chromosomes as the exclusive bearers of hereditary units, this fact must not be assumed as proving that there can be no factors of hereditary significance other than those which are revealed in Mendelian heredity.

Since every cell receives its full complement of chromosomes and of genes, it is necessary that every gene should be divided at each cell division. Figure 77 indicates the manner in which this process may be assumed to take place. Portions of two chromosomes show the genes (1, 2, 3, etc.) in process of division in readiness for distribution to the two new cells resulting from each cell division.

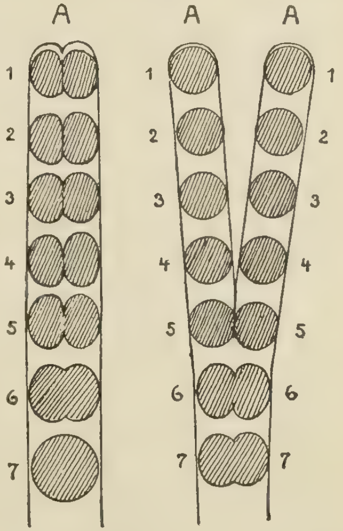


Fig. 77.—Diagram of the division of the genes (1, 2, 3, etc.) in the chromosome *A* preparatory to the division of the latter into the identical daughter chromosomes *A*, *A*.

Evidence that the chromosomes are the bearers of the units of heredity has been furnished in the hybridization of various species of organisms, but especially of bees. It has been shown that in reciprocal crosses of pure bred Italian and Carniolan bees all the females (queens and workers) show the dominant yellow color of the Carniolans. The males (drones) however, always resemble their mother, no matter which way the cross is made. This must happen because the females are always derived from fertilized eggs—bearing both maternal and paternal sets of chromosomes, including color genes—while the males arise from eggs which develop without fertilization and hence carry only the maternal set of chromosomes. The drone, in other words, bears only the inheritance of his mother for the reason that he has no father.

When the hybrid queens, bearing one set of Italian chromosomes and one set of Carniolan, produce drones, half of these are of the Italian color and half of the Carniolan color, for each drone receives one member of the pair of allelomorphic color genes which its mother possesses. This can only mean that the two members of the pair of color genes are separated during the maturation of the eggs of the hybrid queen, half of the mature eggs receiving one member and half the other. The development of a drone from either of these two types of eggs reveals which color it has inherited. In fertilization, when such occurs, all the pairs of genes are recombined to produce the female.

Cytoplasmic Inheritance. While all Mendelian hereditary units are doubtless referable to the genes in the chromosomes it must not be forgotten that the cytoplasm contains self-propagating bodies which are equally important in the differentiation of cells. These bodies, such as plastids of various sort, including chloroplasts, as well as mitochondria, Golgi bodies, and centrosomes, are transmitted from cell to cell and from generation to generation somewhat as are the chromosomes. They too presumably vary somewhat in different hereditary lines of the same species and they must certainly be recognized as constituting a part of the hereditary mechanism.

That their activities are controlled by the chromosomal genes may be conceded without discrediting their importance in carrying on the functions of the cells as physiological units. These cytoplasmic bodies have probably been derived from more simple ancestral types by a long series of evolutionary changes. But it seems not unlikely that this evolution may likewise be ultimately referred to mutations in the genes. If so, then cytoplasmic inheritance is indirectly only a phase of Mendelian heredity.

Cytoplasm and chromosomes are always mutually dependent on each other and only by the harmonious interaction of both can any inheritance take place. In fact the expression of any hereditary characteristic is dependent not only on the participation of the entire protoplasmic system of the organism but of the environment as well.

Types of Mutations

Gene Mutation. Now if, as a result of any accidental or other cause, a change occurs in a single one of the vast numbers of genes which the cell contains, then some alteration of the heredity of the organism, or of that part of the organism to which that cell gives rise, is certain to take place. The mutation may be of a dominant nature, that is, the bodily characteristics determined by the mutant gene may appear in the presence of the normal allelomorph, or it may be recessive, not visibly affecting the body when mated with a normal gene. If the mutant gene be dominant, and in a germ cell, the new characteristic will be expected to occur in every one of the offspring to which that gene and its descendants are distributed through generation after generation as long as that hereditary line exists or until a new mutation intervenes. But if the mutation takes place in a body cell it will disappear with the death of the body, no matter how favorable it may be, unless the individual can be propagated by vegetative reproduction.

If the mutant gene be recessive, on the other hand, the changed character will appear in the offspring only when it occurs in both egg and sperm cell. And, although the genes determine the hereditary characters, it is not correct to say that each visible character of the body is determined by a single gene, for there is evidence that each organ is the result both of the interaction of many genes and of the environment. And it is furthermore probable that each gene affects more than a single part of the body.

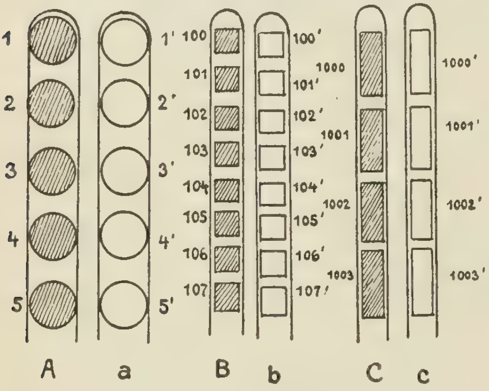


FIG. 78.—Small portions of three pairs of chromosomes, indicating the theoretical arrangement of the pairs of allelomorphic genes in each cell; those of chromosomes *A*, *B*, *C* having been derived from one parent and those of *a*, *b*, *c* from the other.

To understand more fully the processes concerned in a mutation one should have a mental picture of the hereditary mechanism of the cell with its multitude of genes arranged in definite order in the chromosomes. In figure 78 are thus represented portions of three pairs of chromosomes Aa, Bb, Cc, in which the genes 1, 2, 3, 1′, 2′, 3′, etc., are indicated as having a linear arrangement throughout the length of each chromosome. Gene 1 may now be thought of as affecting the eye color, gene 2 as one which influences the hair color, gene 100, on a separate chromosome, the character of the hair, whether straight or curly, gene 1000, in a third chromosome, a certain physiological peculiarity; another is responsible for a mental condition, and so on throughout the entire length of all the chromosomes, until we have included all the hereditary physical, physiological, and mental characteristics of the individual. In this way Morgan and his pupils have plotted the assumed position of over four hundred genes in the four pairs of chromosomes found in a cell of the fruit fly, *Drosophila.*

Now it happens that although these genes are so constituted that they are capable of self-propagation through endless generations, they nevertheless appear to be susceptible to injury and abnormal growth, just as is the cell or the body itself. But the difference between an injury to a gene and an injury to the body lies in the fact that the body eventually dies and with death the injury disappears, while the gene is immortal and retains its injured or changed condition indefinitely. But since this gene aids in determining one or another of the bodily characteristics, all the ensuing generations to which this gene is transmitted must have an altered inheritance and may sometimes show an altered bodily character. A simple illustration will make this plain.

To produce the colored hair on the body, for example, there must be present a certain gene which causes the cell to form an enzyme—or similar substance—which acts on a chromogen base to produce pigment, and if a sufficient amount of this pigment is produced in all the hair cells during growth the hair will be pigmented, black, brown, or yellow, according to the association of genes present. But if this enzyme-producing gene is destroyed, or lost, or for any reason is prevented from acting, then no pigment can be produced no matter how much chromogen may be present. Consequently all the hairs will be without pigment, that is, they will be white from the contained air spaces. And from such albinic animals no colored offspring will ever come if similar ones are bred together generation after generation. The color can be restored by introducing an unchanged enzyme-gene from another line, but the white, or albino, type will reappear just as soon as a pair of the altered genes come together in subsequent generations. Only by the extermination of the entire line bearing the altered gene or by an entirely new mutation can the species be freed from this aberrant type. In nature such albinos are usually eliminated as soon as they appear.

It sometimes happens that the mutation of a single gene may affect several organ systems of the body. If these changes are too pronounced the individual may be hereditarily feeble and short-lived or may even be unable to exist through more than the earliest stages of development. In the former case the line may become extinct in a few generations, while in the latter no hereditary line is established.

In some cases the mutation may affect the genes associated with the sex-determining mechanism, in which case we have examples of sex-linked characters, and if these characters be lethal in their nature a disproportion of the offspring of that line will be of the same sex, due to the death of all individuals of the sex in which the lethal genes are not provided with normal mates. If both members of the pair of sex chromosomes in the homozygous sex bear a different lethal all the offspring that live will be of the same sex. Such a line obviously can be continued only by the introduction of a normal gene from another line in each generation.

It has frequently been found that the same gene may undergo repeated mutations, giving a series of multiple allelomorphs. When the mutant gene itself mutates, a cumulative effect may result, but up to the present time the theory of orthogenesis has received but little support from geneticists. Any multiple allelomorphic series could be arranged in an apparently orthogenetic sequence, but the known history may prove that each member of the series represents merely a more or less divergent mutation of the same normal gene rather than a cumulative genetic series.

Mutation by Non-disjunction of Chromosomes. But there is another type of chromosomal change which involves no alteration in the physico-chemical nature of the gene, but merely an unequal distribution of the genes. And this process will result in the loss of genes in some cells and an excess in other cells. This type of mutation is of relatively frequent occurrence in some organisms and the nature of the process can be confirmed both by genetical and cytological evidence.

When the cells of the body multiply by division, each of their chromosomes divides longitudinally in such a manner as to divide into two equal portions each of the genes of which the chromosome is composed. One-half of each chromosome, containing one representative of each of its genes, passes toward each pole of the division spindle and is thus transferred to each of the two new cells (Figure 79, A, B, C).

Occasionally, however, both members of one of the divided chromosomes pass together toward one pole of the division spindle and thus give one of the daughter cells a double representation of the genes in this chromosome, while the sister cell lacks these genes entirely (Figure 79, A′, B′, C′). The two cells will now differ in their hereditary make-up, for one will have received additional hereditary factors, while the other will be lacking in a corresponding part of its normal inheritance.

Such a process, termed non-disjunction of chromosomes, may occur at any cell division, including those which take place during the formation of the germ cells. In figure 76 is shown a well-known mutation in the fruit fly, involving such a duplication of genes in the sex-determining chromosome (x).

If this unequal division occurs in the germ line and if both of these new types of germ cells survive, and if by fertilization two similar ones form a zygote and if, further, the combinations are compatible for the development of the individual, then there would arise two divergent races, differing in chromosome numbers and in certain characters from each other as well as from the normal individuals of the species. This addition and loss of chromosomes and their constituent genes seems to be of far-reaching importance in evolution.

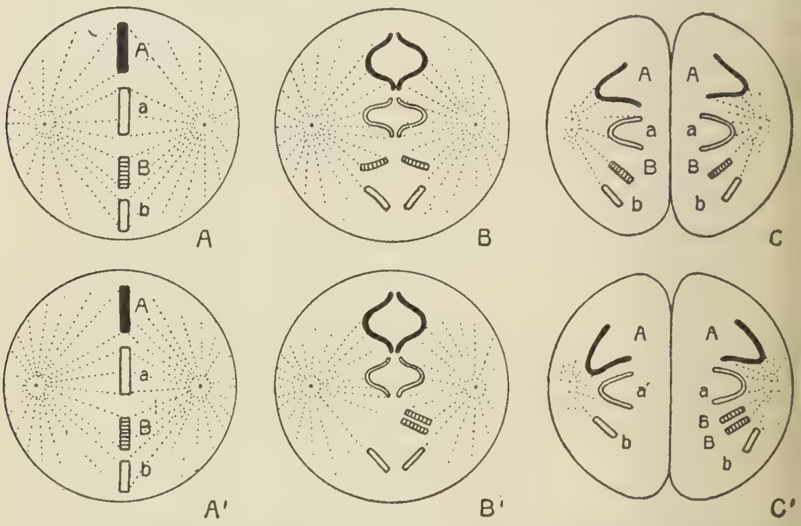


FIG. 79.—Diagrams showing the division of the chromosomes in normal cell division (*A*, *B*, *C*) with an equal distribution of chromosomes *A*, *a*, *B*, *b*, to each new cell. Occasionally a mutation occurs (*A′*, *B′*, *C′*) in which the divided chromosomes are unequally distributed, giving one of the new cells an excess and the other a deficiency in the number of chromosomes and hence in their contained hereditary units.

Large or small parts of chromosomes, instead of entire chromosomes, may be involved in a similar manner. Furthermore, an entire set of chromosomes may be thus duplicated, or even the complete double set, producing triploid or tetraploid varieties. In animals such extensive duplication is usually fatal to the cell, but in the higher plants such varieties are sometimes viable and capable of reproduction as improved varieties of commercial importance. Polyploids, with four or more sets of chromosomes, also occur in nature as distinct varieties or species.

If any of the chromosomes are unequally distributed in the division of somatic cells abnormal parts or tissues may result. If the parts are capable of continued growth, as frequently occurs in plants and sometimes in animals, one portion of the body may be markedly different from the rest. This may form a so-called mosaic, or bud mutation, and in plants which can be propagated vegetatively, or even in some which produce seeds, the mutant type may prove to be of horticultural value. Some of our improved varieties of fruits have thus arisen in recent years.

We may therefore conclude that mutations result from some unusual or abnormal change in the chromosomal constitution of a cell and that if the change is to be hereditary it must occur in a cell of the germ line. In the first type of mutation there is a change in the physico-chemical components of one or more genes and in the second type there is a change in the distribution of the genes.

RECOMBINATIONS OF MUTATIONS

Recombinations of Mutant Genes. Cross-overs, or exchange of hereditary units between the members of a pair of chromosomes, are of frequent occurrence. Thus if the unit for dark hair should lie in the same chromosome as that for brown eyes, then every person who had dark hair would also inherit brown eyes, for both these are dominant characters. But if the other member of the chromosome pair carries the genes for light hair and blue eyes a cross-over between either pair of genes would associate dark hair with blue eyes. In future generations when two similar chromosomes of these new types are brought together the individual will reveal the changed association of the two genes.

Combinations of this sort are not to be confused with mutations, for there has been no change in the expression of any of the hereditary units, but only a new assortment of them. Such associations nevertheless may be of much importance in evolution, for they furnish new combinations of characteristics which will be tested by the environment as to their survival value.

Chromosomal Recombinations. Not only by cross-overs are new combinations of the mutant characters obtained but even more important is the segregation and recombination of the chromosomes themselves at the beginning of each new generation according to Mendel's law of heredity. As a result of segregation the germ cells receive one member of each pair of chromosomes, either paternal or maternal, but never both, and these are brought together in all possible combinations.

Mutation and Evolution

Effects of Mutation. In its effect on the body the mutation may be classed as structural, physiological, or lethal, or any combination of these.

A. Structural. Frequently producing a visible change in some portion of the body.

B. Physiological. Affecting the function without altering the visible form of an organ.

C. Lethal. Either a structural or a physiological mutation may so profoundly affect the individual that it is unable to survive to sexual maturity. Less profound mutations, termed semi-lethals, may so weaken the stock that only a few individuals reach adult life. Obviously the only types of lethal mutations which can be transmitted are of a recessive nature, that is to say, they do not prevent survival when in a heterozygous condition, associated with an allelomorphic normal gene. Only when homozygous, the allelomorphic normal gene being absent, is the recessive lethal mutation capable of preventing survival.

Conversely every mutation in which the lethal gene is dominant to its normal allelomorph results in the death of the individual in which it appears, causing the extinction of the mutation as soon as it occurs.

Many lethals are sex-linked, eliminating half the offspring of one sex or of the other, according to the nature of the sex-determining mechanism of the particular species.

It is a significant fact that a gene mutation affects only one member of the pair of identical genes present in the cell and occurs in only one of the millions of similar cells that the body may contain. If the mutation were caused by any environmental influence, other than distinctly localized and swiftly moving particles such as x-rays or radium emanations, both members of the identical pair and in more than a single cell might be expected to be simultaneously affected. But this seems not to occur. The cause of the single gene mutation therefore is more probably internal than external, and may be assumed to result from some rearrangement of the elements which compose the molecular structure of the hereditary unit.

Time and Place of Mutation. Any cell in any part of the body and at any time in the life history, in the earliest stage of the embryo and in old age, is presumably subject to these genetic changes. But only if it occurs in the germ line and preceding the end of the reproductive period can it be transmitted. Non-disjunction probably takes place most frequently during the maturation of the germ cells, not counting the abnormal mitoses which occur in diseased and weakened tissue cells.

Direction of Mutation. The vast majority of mutations evidently produce such minute changes in the appearance of the individual that they usually escape detection, while others can be distinguished only by a trained observer. Occasionally, however, the changed hereditary unit reveals itself by a profound alteration of some organ or portion of the body. Thus a single genetic change may alter the color of the hair of an animal from black to brown or yellow; another changes the color of the eyes; another causes the entire loss of pigment, changing a dark-skinned person into an albino. A single gene also causes the loss of horns in cattle or the loss of the tail in cats. There are no intergrading steps in the process; the change in the gene is complete when it first makes its appearance, and the effect on the body will be complete when two of these mutant genes become associated.

Antagonistic Genes. When the mutant gene is present in an heterozygous condition, that is, when it is accompanied by a normal allelomorphic mate, its effect on the body is usually incomplete. For in such cases the mutant gene and the normal gene may act in a quite antagonistic manner. When the dominant gene for taillessness in cats, for example, is accompanied by the gene controlling the normal length of the tail, the one tends to prevent the growth of the tail and the other to accentuate the growth to normal proportions. The result is that neither is entirely successful and the animal develops a short tail. In the same way colored flowers heterozygous for the color factor show a decreased pigmentation. Thus the crossing of red and white flowers produce pink ones. But both the red and white types may be recovered in the next generation in the well-known Mendelian ratio.

Progressive and Regressive Mutation. And yet in other cases the mutation may be partial, as in the eyes of *Drosophila,* where, as shown in figure 80, one mutation changes the full eye (F) to the bar eye (B), while a second mutation further reduces the number of facets in the bar to that of the double-bar (U), by transferring both bar genes to the same chromosome. The removal of the bar genes by this cross-over restores the eye genes to the ancestral full-eyed type in the homologous chromosome. But no case is positively known of the return of a mutant gene to its original condition.

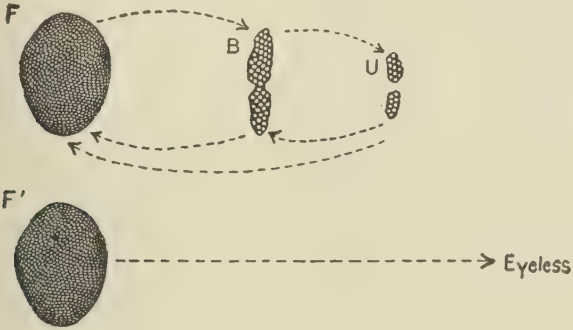


FIG. 80.—Diagram illustrating the reduction in number of facets in the eye of the fruit fly, *Drosophila*. *F*, fully faceted eye; *B*, bar-eyed mutation; *U*, ultrabar-eyed mutation. Arrows represent the directions of mutation. *F'*, fully faceted eye leading by a single mutation to an eyeless race. (After Zeleny).

A different type of mutation, on the other hand, may cause the total loss of the full eye (F′) by a single gene mutation, and without intermediate steps. Now the naturalist who found these four types of flies in nature might assume that they represented an evolutionary series leading from full eye through bar-eye and ultra-bar to eyeless. But such, as we have seen, was not the case, for the series is composed of two quite independent types of mutation.

Increase and Decrease in Number of Digits. An additional digit on the hands or feet of man (Figure 83) is transmitted as an imperfect Mendelian dominant, as are also the supplementary digits in "double-pawed" cats. These occur as a result of a gene which causes the twinning of one of the digits. In other mammals and in poultry similar mutations occur. These mutations are not to be considered as reversions to an ancestral type, nor do they gradually come into existence from small beginnings. The gene responsible for twinning brings forth the new digit fully formed. But only when in a homozygous condition is its effect on the body complete. In cats a supplementary mutation may increase the number of digits to seven or even eight (Figure 81).

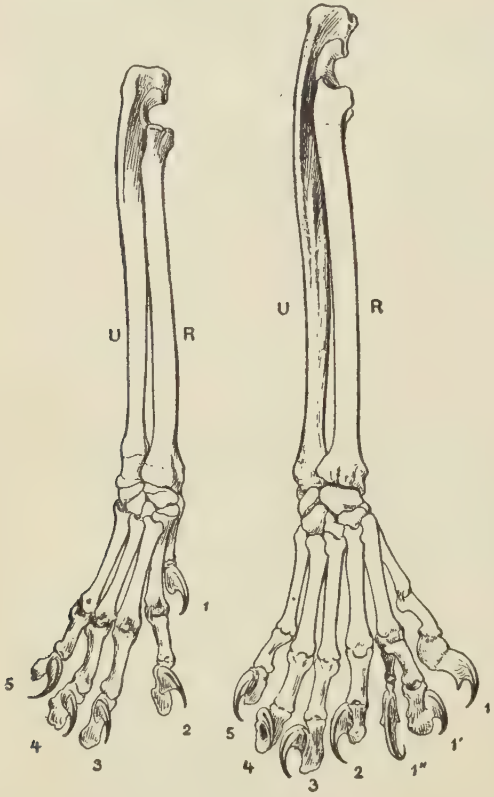


Fig. 81.—Skeleton of fore foot of a normal cat and of a polydactylous or "double-pawed" mutation. The latter is the result of an imperfectly dominant hereditary factor for twinning.

Occasionally, instead of twinning, a mutation appears which causes the fusion of two normal digits. This occurs in the so-called mule-footed pig, the foot of which is shown in figure 82. The two hoofs are here fused together as are also the two median terminal bones. This too is a character which results from a single gene mutation, and since it is dominant to the normal type makes its presence observable at once.

When either the polydactylous or syndactylous animal is mated with a normal footed individual either half the progeny or all of them may be expected to show the mutation, depending upon whether the affected animal received the mutation from one or from both parents. Thus a dominant mutation may spread widely through the normal stock, its survival depending upon the reaction of the environment.

Supplementary digits also occur as a result of twinning due to some disturbance of development, the end result sometimes being indistinguishable from the hereditary type. Only breeding tests or an examination of many relatives can determine which of these types is responsible for the additional digits (Figure 83). The problem is further complicated by the fact that in some hereditary lines polydactylism appears only under certain developmental conditions. In flies likewise the gene for supplementary legs is activated only under a suitable environment and in genetically red flowers the pigment is formed only within a certain range of temperature.

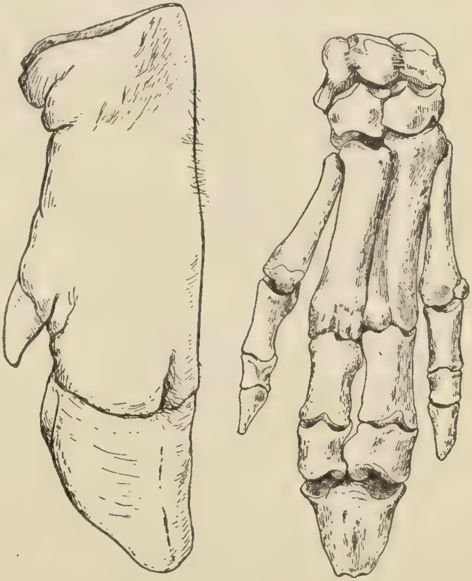


FIG. 82.—External appearance and skeleton of the foot of a syndactylous mutation of the domestic pig, the so-called mule-footed pig. The hoofs of the two large toes are fused together, but the bones remain separate except for the fusion of the terminal phalanges.

Cause of Mutation. The progress of organic evolution seems to be mutually dependent upon the instability of the hereditary mechanism on the one hand and on the action of the environment in eliminating unsuitable mutations on the other. It has long been a matter of speculation as to whether the mechanism itself is capable of being influenced by any of the environmental forces or conditions.

Thousands of experiments, some of them extending over long periods of time, have been made with the view of solving this problem, but none of them have been conclusive. An abnormally high temperature has been shown to increase the rate of mutation in *Drosophila,* and alcohol, lead and other protoplasmic poisons have been thought to injure the germ plasm to such an extent as to lead to malformations of an hereditary nature in mammals.

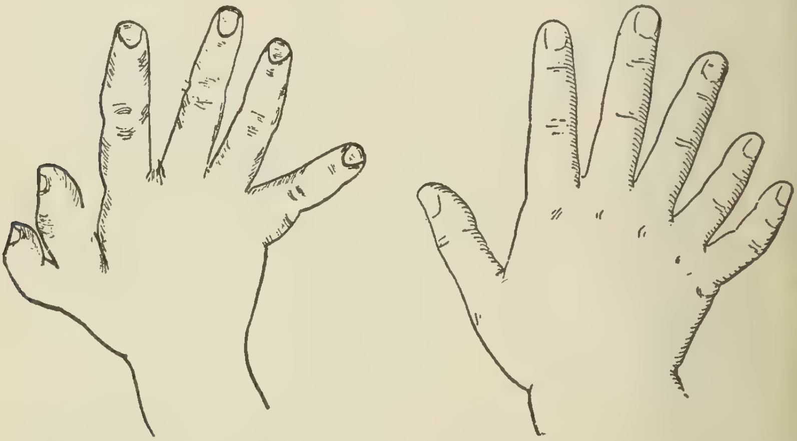


FIG. 83.—Polydactyly in man. The hand with the twinned thumb is from a person known to inherit this defect as a mutation, while that with the twinned little finger is from a person not having similarly affected relatives, and presumably represents merely a defect in development. (From Milles in Journal of Heredity.)

Experimental Production of Mutations. Quite recently, however, a method has been found to speed up the production of mutations to an almost incredible degree. This method makes use of rapidly moving particles such as radium emanations or x-rays, and the procedure has now become standardized so that it can be widely used with a high probability of success.

These rays have long been known to cause sterility in organisms by injury to the germ cells and if in too concentrated a form the death of all the cells follows. If, however, the application be of exactly the appropriate strength and duration the genes themselves may be affected without other apparent injury to the cell. By x-raying the sperm cells of *Drosophila,* either within the body of or after they have been transferred to the sperm receptacle of the female, Muller has been able to speed up the mutations in this fly to 150 times the ordinary rate. Treatment of unfertilized females is equally effective in causing mutations both in the young germ cells and in the mature egg. All types of mutation that naturally occur with such extreme slowness can now be obtained by the experimenter more rapidly than he can study them. Some are lethal, some are physiological and others result in visible physical changes indistinguishable from those which have been found under normal conditions.

Other investigators have produced similar mutations in corn and other plants, with the hope of securing new types which may become the foundation stocks of improved and more prolific varieties. The possibilities in this direction seem to be almost without limit. It has been claimed that the control of evolution is at hand. As many new types can now be secured in one summer as unguided nature would have produced with the same number of organisms in a century.

The theoretical explanation which has been given to account for these changes is that the rapidly moving particles which constitute the ray strike the gene in such a manner as to alter its physico-chemical structure, possibly by a rearrangement of the atoms of one or more molecules. Its nature is thereby changed and its future activities modified in such a manner that when the time comes for it to exert its influence with the other genes in controlling the development of some part or parts of the body it fails to respond in a normal manner. A changed organism consequently results. In other cases the rays cause the chromosomes to break in fragments, resulting in mutations of the non-disjunction type.

The speeding up of mutations means a similar increase in evolutionary progress which depends upon them, and it has been suggested that the course of evolution in the past has been due in part to the natural emanations of radioactive substances in various parts of the earth.

Frequency of Mutation. Visible results of mutations either of the gene or of chromosomal arrangement occur naturally only at very long intervals in any hereditary line. The physico-chemical structure of the gene is relatively stable and the marvelously delicate mechanism of cell division only rarely fails to distribute to each of the two resulting cells precisely equivalent portions of the spontaneously divided chromosomes and genes.

Even in the fruit fly the total number of genes which have been known to change is probably but a small fraction of those that have remained stable. And this in spite of the fact that the flies have been bred in almost countless numbers and for many years. Presumably, however, during these same years a vastly greater number of similar mutations have occurred among the wild flies of the same species, but which have not survived for the reason that none of them proved to be as well fitted to their surroundings as are those of the normal type.

Of the few hundred mutant genes recorded, some seem to be more stable than others, the mutation having been observed but once, while others have shown independent mutation several or many times.

Zeleny found from 28 to 61 mutations in each hundred thousand fruit flies. This number is vastly in excess of that found in any other organism, however, and concerns a species in which more than 400 distinct mutations have been recorded during the last few years. It is the great stability of the gene that is remarkable, rather than its occasional mutation. So relatively infrequently does a change occur that it has been estimated that even in this fly more than a thousand years of breeding at maximum rapidity would be required before every one of its component hereditary units would be affected.

Isolation. A group of individuals isolated from the ancestral stock has the most favorable opportunity for a rapid evolution due to the probability of inbreeding and thus establishing pure races of the mutations which may occur or which may already be present but obscured by dominant genes. For this reason remote islands and other isolated bodies of land or of water almost always have varieties or species of organisms peculiar to themselves. Barriers of any sort, as mountain ranges and deserts, frequently separate so-called geographical races.

Hybridization. Eventually two or more of these geographical varieties or local races may be brought together to furnish new combinations which are again tested by the environment as to their fitness for survival.

Species crossing brings together the greatest possible variety of genetic combinations and when the offspring of such hybrids are fertile their progeny show great variability. Among them may be some with hereditary combinations far superior to those of either of the ancestral stocks, and these may go forward with very rapid evolutionary progress.

Sterility. The diversity of forms which successive mutations produce are frequently prevented from merging into a heterogeneous group because of mutual infertility. The identity of species is thereby maintained.

The factors which prevent the intermingling of species are, first, the lack of sex attraction which frequently prevails; second, the inability to mate due to difference in size or structure; third, infertility when mated; and fourth, sterility of the hybrid offspring in cases where the two parent species are occasionally fertile. All of these factors are the result of accumulated mutations, but the first and second require no further explanation here. The third and fourth, however, have a chromosomal basis which throws some light on the nature of the processes which occur in mutations.

The horse and the ass, for example, are known to have descended from the same ancestral stock and are fertile in reciprocal crosses. The ordinary mule, however, is the offspring of the male ass and the mare. Mules possess apparently normal reproductive organs and have strong sex instincts, but they are not known to be fertile with each other. The male mule is also infertile with both parent species, and this is also generally believed to be true of most of the females.

The cause of this infertility has been carefully investigated by Wodsedalek, who found that while the two chromosome sets of the parents work together harmoniously in the cell which compose the mule's body, they prove to be incompatibl at the time when homologous chromosomes unite in pair preparatory to the maturation of the germ cells.

Not only are the numbers of chromosomes in the two paren species widely different, so that the members of the two set cannot all find mates but, even more important, only a few o those present form any union at all. The process of maturation is thereby interrupted and few, if any, functional germ cells are formed.

In the synaptic union of chromosomes, which occurs in th maturation of the germ cells, the homologous chromosome come together in pairs, and the genes derived from the tw parents lie side by side. If mutations in either of the paren species have increased or decreased the number of chromo somes derived from the ancestral stock then harmonious synapsis cannot occur, and irregularities of chromosomal distribution would result if any germ cells were to be formed. Added to this is the probability that other mutations have changed the arrangements of the constituent genes on the chromosomes or so altered the nature of some of the genes that synapsis becomes impossible.

At rare intervals it may happen that in the female mule a chance chromosomal distribution may result in the formation of an egg capable both of fertilization and development. In fact, a female mule is known to have produced one colt sired by a stallion and another colt sired by an ass. Hence it is not inconceivable that selection of suitable hereditary types may eventually lead to the production of a breed which is regularly fertile.

Experimental Evidence. It has sometimes been claimed that the evidence obtained from the experimental breeding of cultivated plants and domesticated animals is not valid for species in their natural environments. The ancestral stocks of many domesticated breeds are quite unknown and there seems little doubt but that some of them are hybrids of two or more wild species.

To meet these objections Sumner collected several distinct subspecies of mice belonging to the genus *Peromyscus* and placed them together under identical environmental conditions near the sea-coast at La Jolla, California. The subspecies from the mountains differs in many particulars from the one collected from the desert, and both are easily distinguished from the form native to La Jolla. If the moist coastal climate had been directly effective in influencing the evolution of the native variety it might be reasonable to expect that the two imported varieties would show at least a slight approach to the native variety in one or more characteristics. After many generations extending over six to eight years, however, not the slightest indication of this could be detected. Even an artificially high temperature and low humidity failed to exert any measurable influence in changing the heredity of these mice. Nor is there any reason for believing that a hundred years of changed environment would show a different result.

And yet out of the breeding stocks there arose spontaneously—or more probably made their presence manifest through inbreeding—a number of distinct mutations which became the foundation stocks for the establishment of entirely new color varieties of the wild species. Now if any of these new color varieties should be liberated in environments in which they prove to be well adapted it may reasonably be expected that their descendants would be classified as distinct subspecies by naturalists of future generations.

Hairlessness appeared in two different lines and a breed was established in which the animals become almost entirely bald soon after birth and remain so throughout life. The breed is still in existence.

That, it seems reasonable to believe, is the way in which varieties and species behave in nature. Inbreeding brings to light such recessive mutations as may have occurred in the stock in past generations and the environment tests the fitness of the resulting bodily characteristics. The crossing of diverse strains gives rise to endless combinations of these characteristics and each of these combinations is similarly tested. That is exactly the way in which our improved breeds of domesticated animals have been produced and this is equally true of our cultivated plants. It is also nature's way. It is doubtless the method of evolution. Much time is required and there are many failures, but nevertheless progress is made as the marvelous diversity of animal and plant forms will testify.

It seems quite unnecessary to appeal to any mysterious force which may be supposed to keep each of the hereditary units informed as to the conditions outside the body or even as to the changes which may take place in the body itself. Much less is it reasonable to expect that such conditions may directly influence any particular unit so as to cause it to modify its activities in the direction and to the extent that would be required to keep all the individuals of successive generations attuned to their environment.

A changed environment does not produce new mutations; it can only select out of the vast numbers of hereditary stocks already present those which on the whole are most suitable for survival.

In conclusion it may be added that the cell has evolved into an extremely complex reaction system, with its parts differentiated and specialized for the performance of a great variety of functions. Not the least important of its activities are the processes concerned with reproduction and with the transmission of its characteristics to its descendants. The hereditary mechanism is evidently in very delicate adjustment and its units not entirely stable. At long intervals the physicochemical relations of one after another of these units are modified in some manner or the balance between different groups of these units is disturbed. A new type of reaction results, and this may affect not only the cell in which the change occurs but also the descendants of that cell in all subsequent generations. In multicellular organisms the effects on the body may be very pronounced and the relations between the organism and its environment may be greatly altered.

The survival of this mutation means one step forward or backward in the progress of evolution. Given a sufficient length of time the evolution of all organisms from a single primordial unit by the accumulation of successive mutations seems entirely plausible.

INDEX

Ability, intellectual, 403
  inventive, 341
Aborigines, American, 342
Acceleration, prepubertal, 217
Acheulian, Epoch, 282, 285
Acquired characteristics, inheritance of, 388, 389, 443
Acromegaly, 212
Actions, intelligent, 253, 262
  mechanical, 253
  reflex and instinctive, theory of the origin of, 255
  tropisms, 253
  volitional, 248
Activities, control of bodily, 232
Adams, Henry, 274, 276
Adaptation, intelligent, 254
Adaptive reactions, 261
Adjustment, automatic, 328
  cultural, 314
  Darwinian theory of, 304
  human, 312
  intelligent, 267, 328
  material, 311
  physiological, 346
  societal, 314
Adjustors, 232, 234
Aeroplanes, 368
Africa, deserts of, 338
  grasslands, 375
  racial amalgamation in, 408
  use of iron in, 376
Age, Bronze, 276, 282, 285, 294, 295, 296, 298, 299, 302
  Chellean, 170
  Ice, 277, 278, 279, 280, 288, 300, 301
  Iron, 276, 285, 299, 302
  machine, 275
  Mesozoic, 167
  Neolithic, 302
  New Stone, 275, 301
  of Metals, 298, 301
  of *Pithecanthropus*, 163
  Old Stone, 275, 281, 300
  Pliocene, 157
  Steel, 300
  Stone, 276, 285, 296
  Tables, 46, 151, 285
  Upper Siwalik, 164
Ages, Middle, 283
Agriculture, 372
  beginning of, 371
  California, 343
  development of, 373
  early, 375
  resources of, 342
  rise of, 370
  tropical, 378
Air currents, changes in, 74
Alabama, 332, 333
Alaska, 345
Alchemists, 83, 96
Alertness, 346
Algæ, 65, 114
Alimentary canal, development, 197
  organs developing from, 200
Alinements, 299
Allantois, 127, 129
Allelomorphic series, 426
Allelomorphs, 419, 423
  multiple, 426
Allen, F. J., 102
Allosaurus, 134

a Centauri, 7, 8
Alps, 75, 337
Alterations, chemical, in senescence, 219
Alumina, 101
Alveolar substance, of protoplasm, 84
Amalgamation of races, 407
Amalgamation, tendency to, 408
Amber, 299
Amblypods, 135, 137
Ameghino, F., 158
America, 368
  aborigines of, 342
  North, 278
American Indians, 373
American School of Prehistoric Research, 302
Americans, 362
  early, 344
  typical, 407
Amiens, 282
Amino acids, 86
Ammonia, 100, 103
Ammonites, 74
Ammonium carbonates, 108
Amnion, 127, 129, 205
Amniotic cavity, 191
Amœba, 253, 260, 385
Amphibia, 126
  origin of, 67, 112
Amphioxus, 118
Amulets, 296
Analogy, 307
Anatomical variations, 223–226
Angles, 340
Animal, consciousness, theory of, 260
  behavior of, 256
  fitness, 313
  intelligence, 252–260
  life, changes in, 252
  reactions, 269
  size, 211
Animals, domestication of, 293
  grass-eating, 374
  invertebrates, 187
  lime-secreting, 114
  mammals, 187
  metazoa, 187
  pack and draft, 299
  protozoa, 187
  use to man, 374
  vertebrate, 187
  wild, taming of, 373
Ankylosaurs, 133
Annapolis, 356, 362
Annelids, 114
Anomalies, 332
Ant, instincts of, 256
Anthropoids and man, Huxley's comparison, 309
  phylogeny, 184
Anthropophagy, 322
Anti-bodies, see Hormones
Antiquity, Crawford, 302
Antiquity, means of determining, 156
Apes, anthropoid, 140, 142
  origin of, 112
Appalachian Mts., 79
  revolution, 112, 128
  trough, 79
Appendix, comparison of, in various animals, 222
  vermiform, 221, 222
Arabia, 338, 340
Arboreal habitat, 143
Archæocyathinæ, 114
Archaeornis, 130
Archean, beginning of, 43
Archeozoic era, 46, 51, 57, 65
  sediments, thickness of, 63–69
  time ratio of, 69
Archipallium, 194, 241
Archives de l'Institut de Paléontologie Humaine, 302
Areas, association, of brain, 268
  frontal, of brain, 268
Aridity, 124, 127, 128, 130, 137, 344
  Devonian, 144
  Miocene, 144, 147

  Mississippian, 145
  Permian, 145
  Pliocene, 144
Aristotle, 87, 90, 92, 229
Arizona, Hopis of, 372
Arm, 274
Arrhenius, S., 98, 99
Arshkot-i-Tarik, 303
Art, Aurignacian, 182
  cave, 290, 291
  Crô-Magnon, 180
  healing, 296
  Paleolithic, 291
  textile, 295
Arteries, development, 200
  hardening of, 218
Arteriosclerosis, 218
Arthropods, 115
Artifacts, metal, 298
Artist, cave, 292
Asia, 278, 338
  as theater of mammalian evolution, 143
  birthplace of mankind, 152
  deserts of, 338
  dessicated, 375
  grasslands, 375
Asiatics, 362
Ass, 374, 440
Association areas of brain, 268
Association, British, Advancement of Science, 302
  inheritance, 389, 395
Assortative mating, 401
Asteroids, see Planetoids
Asthenosphere, 41
Atmosphere, 55, 58, 76, 81
  in Archeozoic, 65
  of growing earth, 52
  of water-gas, 35
  origin of, 52
  primordial, 34
Atmosphere and Man, Committee on, 357
Atmospheric blanket, of earth, 55
Atoms, 101, 102, 103
Attica, New York, 158
Auricle, of heart, 199
Aurignacian Epoch, 151, 285, 300, 303
Australia, 337, 340
Automobiles, 368
Ax, paleolithic hand, 283
Axes, hand, 289
Azilian, 293

Bacillus bulgaricus, 219
Bacteria, 97, 98
Bagehot, W., 323
Baker, H., 92
Balanoglossus, 118
Banderlog, the, 257
Banolas, Spain, 171
Barbarism, 342
Barrell, J., 47, 48, 51, 57, 69, 111
Beasts, 344
Bee, instincts of, 256
Bees, 91
  Italian and Carniolan, 422
Beetles, 91
Behavior of animals, 256
  of man, 268
  instinctive, 253
  intelligent, 258, 270
Belgium, 348
Bell, A. G., 404
Berlin, 382
Bichat, M. F. X., 87
Biochemists, 86, 96
Biogenesis, history of, 90
Biological selection, 380
Biology, 83, 347
Bipedality, cause of, 130, 131
Birds, evolution of, 128
  first recorded, 112, 130
  nesting instincts of, 256
  origin of, 112, 129, 146
  toothed, 67, 130
Birth, 208

Birth control, 404
  effects of, 405
Birth-rate, 403–406
  American scientists, 404
  of college graduates, 403
  of intellectual classes, 403–406
  Phi Beta Kappa, 404
Birth, ratio to deaths, 406
Births, multiple, 210
  proportion of male and female, 210
Bison, incised on limestone, 294
Black Belt, 332, 334
Blainville, D. de, 87
Blood, composition of, 347,
  temperature of, 361
Blood cells, development, 200
  natural history, 200
Blood vessels, development, 200
"Blue baby," 208
Blumenbach's classification, 188
Boat, Neolithic dugout, 295
Body cavity, see Cœlom
Body proportions, changes in during growth, 213
Body wall, formation of, 210
Boleophthalmus, 121
Bone, growth of, 215
  growth shown by madder, 215
Bones, cranial, ossification of, 203
Boucher de Perthes, 283, 284
Boule, Marcelin, 171
Boy, growth of, 215–217
Brachiation, 141
Brachiopods, 114
Brahmans, 337
Brain, 274, 275
  cortex, 241, 268
Brain cells, number in cortex, 241
Breaks, geologic, 71, 72
Breeding, experimental, 441
Breeds, domesticated, 441
Breuil, l'Abbé, 181, 300, 301
Britain, migrations, 340
British, 362
British Isles, 286
Broken Hill mine, Rhodesia, 176
Brontosaurus, 131
Bronze Age, 150, 276, 282, 285, 294, 295, 296, 298, 299, 302
Bronze, art of casting, 298
  metal, 283
  trumpet, 297
Brooks, C. E. P., 339
Browne, Sir Thomas, 91
Browsing mammals, origin of, 112
Buffon, Comte de, 93
Bushmen, Africa, 159
Butterflies, 91

Cacops, 126, 127
Cæcum, 221, 222
  comparison in various animals, 222
California, 343, 344, 352, 353, 355, 356
  Indians of, 341, 343, 344
  La Jolla, 441
Cambrian period, 46, 80, 112, 114, 119
Camels, 75, 137, 138, 374
Campbell, W. W., 11, 21
Canada, vigor of, 340
Canadian period, 77
Cancer, 213
Cannibalism, 314, 322
Capacity, human, intellectual, 270
  mental, 331, 364, 403
Capacities, latent, 345
Capillaries, development, 200
Carbohydrates, 85
Carbon, 76, 103, 247
  compounds, 101
Carbon dioxide, 34, 35, 38, 44, 51, 52, 53, 55, 58, 103, 105, 106, 347
  as climate regulator, 53
  in Archeozoic, 65
  resupply of, through volcanoes, 53
Carbon monoxide, 34, 35

Carbonic acid, 100
Cardan, G., 90
Carnivores, 137
Cascadian revolution, 111, 112, 147
Catalysis, 105
Catholicism, 322
Cats, digits, 434
  " double-pawed," 433
  skeleton, fore-foot, 434
  taillessness, 432
Cattell, 404
Cattle, 343
Cattle-raisers, 374
Cave artist, 292
Cavern, Last Hope Inlet, 158
Caves, 301, 303
Celibacy, 401
Cell division, see Mitosis
Cells, 88, 95, 103, 106, 107, 187, 419, 420, 421, 422, 429
  interstitial, 245
  potential immortality of, 99
  reaction system, 443
Celts, 340
Cenozoic era, 46, 67, 74, 75, 77, 80, 111, 112
  sediments, thickness of, 67, 69
  time ratio of, 69
Centrosome, 422
Cephalopods, 115, 116
Ceratopsia, 132
Cereals, 370, 371
Cerebral cortex, 241
  atrophy, 219
  center of sensation, 230
Cerebral sacs, 193
Cetacea, 116
Chalks, 59
Chamberlin, T. C., 21, 24, 25, 48, 52, 117
Chamberlin and Moulton, on the nebular hypothesis, 12
  planetesimal hypothesis of, 13, 48
Changes, cultural, 281
  retrogressive in various organs, 221–223
Character, racial, 332
Characteristics, acquired, inheritance of, 388, 389, 443
  of soma, 389
Characters, dominant, 429
  hereditary, 424
  lethal, 426
  sex-linked, 426
Chariots, 299
Chazyian period, 77
Chellean, 151, 285, 300
Chemical elements, essential to life, 106
Child, change in proportions, 213
Chimpanzee, 140, 141, 143
  fossil, 168
China, 338, 366, 370, 371
Chlamydosaurus, 131
Chloroplasts, 422
Chordates, evolution of, cause of, 117
  first recorded, 120
Chorion, 205
Chromogen, 425
Chromogen-gene, 426
Chromosomal basis, for sterility, 440
Chromosomal constitution, 429
Chromosomal recombinations, 430
Chromosomes, 419, 420, 423, 424, 425, 427, 428, 429, 430
  bees, 422
  homologous, 433, 440
  mules, 440
  non-disjunction, 427, 431
  polyploids, 429
  synapsis, 440
  tetraploid, 428
  triploid, 428
Chronological table, 151
Chronology, European, 150
  prehistoric, 275, 279, 280, 281, 301
Cimbri Teutons, 340
Cincinnati, 278
Cincinnati uplift, 63

Cincinnatian period, 77
Circulation, change at birth, 208
Civil War, 334
Civilization, 263, 312, 338, 345, 390
  Coldward March of, 364, 380, 381, 382
  contribution to, 373,
  distribution of, 362, 363
  drama of, 280
  European, 263
  evidence of, 266
  evolution of, 364
  hunter stage of, 290
  measured by, 294
  pre-Columbian, 158
  progress of, 371, 383
  retrogressive selection of, 400–403
Civilization and Climate, 362
Civilization, Ecology of, 378
Clarke, F. W., 53, 55, 57
Clarke, Dr. J. M., 158
Classes, hereditary, 402
  intellectual, birth-rate of, 403–406
Classification of human races, 188
  Thomsen's, 276
Clay, Lower Boulder, 301
  Upper Boulder, 301
Cleft palate, 205
Climate, 331, 335, 342, 344, 347, 364, 368, 377, 379, 382, 383
  adjustment to, 361
  best type for man, 365
  California, 356
  changes in, 54, 79, 81, 112
  changes in, as cause of extinction, 132
  Cretaceous, 56, 133
  effect of, 341, 346, 362
  Eocene, 56
  Glacial, 340
  ideal, 356
  Liassic, 56
  Permian, 52, 56, 128, 130, 146
  Pleistocene, 56, 111, 112
  Proterozoic, 52, 56
  limitation of, 345
  physiological effects of, 364
  reactions of, 378
  relation to, 339
  response to, 361
  Silurian, 56
  Triassic, 56
  variability of, 355
Climate Through the Ages, 339
Climates, ancient, 52, 53, 56
  glacial, 56, 74, 111, 128, 144
Climatic conditions, 366
Climatic pulsations, 381
Climograph, of California, 351
  of deaths, 358, 359
  of France and Italy, 350
  of northeastern United States, 349
Climographs, 348, 357
Clothing, 344, 346
  discoveries, 365
  necessitated by Glacial period, 144
Coal, 67, 68, 344, 345, 364
Coccyx, 225
Cochlea, 196
Code, new, of adjustment, 322
Codes, collision of, 322
  rational selection of, 324
Cœlenterates, 114, 115
Cœlom, 192
Cold, increase in, influence of, 128
Collisions, among planetary nuclei, 33
  among stars, 23
Colloidal suspension, life elements in, 107
Colloids, 101, 102
  characteristics of, 102
Collyer, 184
Columbus, 343
Comanchian period, 47, 80, 112, 132
Combinations, Mendelian, 386, 387, 418, 430, 439, 442
Commerce, growth of, 299

Committee, on Atmosphere and Man, 357
Communal life, 145
Competition, between societies, 321
  tragedies of, 323
Complexification, in matter, 101
Complexity, law of, 102
Condition, biological, interplay, 377
Conditions, climatic, 344, 353
  optimum, 346, 347
  social, 335
Conduct, 312
  rational, 253
Condylarths, 135, 137
Congenital imperfection, 399
Conglomerates, 59
Conifers, 67, 74
Connecticut Valley footprints, 131
Consciousness, and experience, 261
  and intelligence, 260–262
Continents, areal variability of, 79
  elevation of, 72, 74, 76, 137
  in Archeozoïc, 65
  origin of, 50
  permanency of, 51
  when largest, 74, 77
Control, voluntary, lack of in certain actions, 254
Convection currents, 35, 37
Conversion, sexual, 245
Conviction, *ex parte*, 326
Cooker, modern, 366
Cooking, discovery of, 365
Coomb Rock, England, 301
Coördination, biochemical, 107
Copenhagen, 362, 382
Copper, 298
Corals, 115
Cores, flint, 288, 290
Corn, 372
  mutations, 437
Cortex, of brain, 268
  cerebral, 241
Coryphodon, 137
Cosmic time, 46, 48
Cosmozoa theory, 96
Cotton, 334
Counter-selection, 313
Crabs, land, 121
Cradle, human race, 278
Cranial sutures, disappearance of, 215
Crawford, O. G. S., 302
Crayfish, 347
Creation, Mosaic account of, 148
Creator, 109
Creeping, sea-anemone, 236
Creodonts, 136
Cretaceous period, 46, 77, 80, 112, 133, 146
  climate of, 56, 133
  in North America, 78
Cretinism, 212
Critical periods, 74, 82
Crô-Magnon man, 179, 280, 287, 289
  art, 181, 288
  decline, 182
  implements, 181
  size, 179
  skull, 179
  skull and face, 180
  skull, compared with Neandertal man, 173
Crocodiles, 132
Croixian period, 77
Cromlechs, 299
Crops, 337, 342, 344
Crossopterygii, 123
Cross-overs, 429, 430, 433
Crust of earth, granitic, 34
Crustaceans, 121
Crustal density, relation of, to ocean basins, 39
Crystallization, fractional, 37
Crystalloids, 102
Crystals, basic, 37
Cultural adjustment, 313, 314
  societal, 313
Culture, Aurignacian, 303

  Crô-Magnon, 288
  Mesolithic, 292, 301
  Neolithic, 293
  Paleolithic, 301
Custom, 314
Current, prehistoric, migratory, 303
Cyanogen, 100
Cycads, 67, 74
Cyclostomes, 121
Cynodonts, 129
Cysts, 97, 98
Cytoplasm, 421, 423

Daly, R. A., 32
Dana, J. D., 51, 69
"Dark Cave," 303
Darling Downs, Australia, 159
Darwin, C. R., 109, 283, 306, 309, 345, 376
  formulation of natural selection, 390
  on variation, 388
Darwin and modern science, 309
Darwinian factors, 308, 314
  theory, 309
Dawson, Charles, 167, 170
Death-rate, 352, 353
Deaths, climograph of, 358, 359
  in New York, 356, 357
  number of, 347, 352
  ratio to births, 406
  study of, 348
  white, 360
Deer, 137, 138, 292
Degeneracy in certain families, 400
Degeneration, senile, see Senescence
Denmark, prehistoric food, 294
Dentition, 223
Denudation, 59, 60
Deposition, rate of, 70
Deposits, cycles of, 59
  glacial, 55, 57
  organic, 59
  salt, 32
Derham, W., 92
Dermis, 204
Descent of man, Darwin's, 307
Destiny, mankind, 397
Development, social, form of, 396
  early prenatal period, 190–193
  later prenatal, 193–211
  postnatal, 211–218
Devonian, Lower, 124, 145
  period, 46, 77, 80, 112, 123
  period, aridity in, 144
  period, diastrophism in, 123
  Upper, 145
Diastrophism, 51, 111, 119, 134
  Devonian, 123
  Miocene, 147
  Mississippian, 126
  Pennsylvanian, 128, 146
  Silurian, 123, 145
Dicrocynodon, 134
Diet, of Pueblo Indians, 342
Differences, racial, causes of, 331
Differentiation, and extinction, 393
  relation to regeneration, 213
Digits, number of, 433
  twinning, 433, 435
Dimensions, prehistory, 276
Dinocerata, 137
Dinosaurs, 74
  ankylosaurs, 133
  armored, 131, 133
  associated with peneplanation, 134
  bipedal, 130
  carnivorous, 131, 133, 134
  Ceratopsia, 133
  duck-billed, 133
  effect of, on mammals, 134
  evolution of, 146
  expansion of, 146
  extinction of, 132, 133, 135
  nodosaurs, 133
  origin of, 112, 130
  Sauropoda, 112, 131, 133, 146
  Stegosauria, 131

  Theropoda, 131
  trachodons, 133
  unarmored, 133
Diplodocus, 131
Dipnoans, 122, 123
Diprothomo, 157
Discussion, Age of, Bagehot, 323
Diseases, 369, 379
  contagious, 352, 353
  non-contagious, 360
Disruption hypothesis, of Chamberlin and Moulton, 12, 13, 47, 48
Dog, 373, 374
Dogs, mental inheritance of, 379
Dolmens, 298
Double-breathing, 121
Dromocyon, 136
Drones, 422
Drosophila, 387, 420, 425, 432, 436, 437, 438, 439
Dubois, Dr. E., 160, 162
Düssel, Germany, 171

Ear, development, 196
  vestigial muscles of, 221
Earth, age of, 58
  as a planet, 5
  atmospheric blanket of, 55
  crustal readjustments in, 79
  diameter of, 49
  effect of moon on, 28
  effect of, on moon, 30
  evolution of, 47, 95
  granitic crust of, 34
  growing, atmosphere of, 52
  -growth, by rapid infall of planetoids, 25
  -growth, by slow accretion of planetesimals, 24
  -growth, in Formative era, 48
  internal heat of, 49, 50
  -knot, 48
  -moon knot, 19
  negative areas in surface of, 51
  origin of, 47
  outer shell of, 40
  passage of, from molten into rigid state, 36
  place of, in universe, 4
  positive areas in surface of, 51
  primordial molten state of, 26, 33
  readjustments in, 71, 72
  shrinkage of, 49, 71, 72, 81, 110
  sub-crustal shell of, 40
  tidal strains in, 30
  warping of, 71, 110
Earthworm, nervous system, 233
East Anglia, England, 183
Ebert, Max, 302
Echinoderms, 115
Ecology of Civilization, 378
Ectoderm, 191
  derivatives from, 191
Education, eugenical, 411
Education, Henry Adams, 304
Education, importance of, 413
  in relation to mores, 320
Eels, 91
Effect, coöperative, 387
  of climate, 362
Effectors, 233
  sea-anemone, 237
Efficiency, man's, 346
Egg cells, 127, 244, 390, 419, 420, 421, 424, 441
  development, 190
  fertilization, 189, 190
  potency of, 385
Egypt, 277, 338, 371, 383
Ehringsdorf, Germany, 171
Elements, chemical, freedom of action in living matter, 248
  chemical, organized in nervous protoplasm, 248
  of animal body, 247
Elephants, see *Proboscidea*
Emanations, radioactive, 438

Embroidery, 295
Embryo, circulation, change at birth, 208
  condition, at birth, 209
  development *in utero*, 205
  prenatal conditions, 208
Embryonic area, 191
Emigration, from Germany, 337
  from Ireland, 337
Emotion, 324
Emotionalism, 395
Emotions, 296
Empire, course of, 367
Endocrine organs, 197, 243
Endoderm, 191
  derivatives from, 191
Energy, 345, 348, 364
  distribution of human, 363
  electric, of chemical elements, 106
  heat, 106
  physical, 346
  surplus, 346
"Energy traffic," 86, 103
England, 289, 382
  Coomb Rock, 301
  Lower Boulder Clay, 301
Environment, 331
  changes in, 74
  cultural, 275
  diverse of man, 310
  fitness of, 89
  physical, 380
  social, 336
Environment and mutations, 388
Environmental forces, 436
Enzyme theory, of Troland, 104
Enzymes, autocatalytic, 104
  catalytic power of, 105
  evolution of, 107
Eoanthropus dawsoni, 167–170
Eocene time, 46, 112, 138, 139, 146, 147
  climate of, 56
Eolithic period, 150
Eoliths, 150
Eopaleozoic time, 80
Epidermis, 204
Epoch, Aurignacian, 281, 303
  Glacial, 278, 337
  Hallstatt, 300
  interglacial, 278, 301, 339
  La Tène, 300
  Mousterian, 300
  Pliocene, 280
  Pre-Chellean, 301
  Riss Glacial, 301
  Riss-Wurm, 300, 301
Era, historic, 279, 282
  prehistoric, 279
Eras, duration of, 69, 70
Erosion, 32, 40, 55, 57, 58, 59, 61, 71, 77, 79, 111
Erpetoichthys, 123
Eskimos, 337, 341
Eugenics, 379, 402
  importance of, 413
Eugenists, 326, 414
Europe, 278, 289, 339, 357, 376, 382, 383
  central, 338, 339, 340
  dominance of, 382
  glaciation of, 338, 375
  metal stoves of, 366
  northwestern, 337, 338, 339, 340
  prehistory of, 302
  races of, 360
  Western, 292, 303
Europeans, 360
  Latin, 362
  Teutonic, 362
Evolution, 74, 99, 364
  an adjustment, 305
  and mutation, 418, 430, 443
  and natural selection, 390
  and progress, 305
  causes of, 385, 386
  crises of, 113
  cultural, 274

  cycles of, 81, 82, 385
  directions of, 391, 397
  drama of, 384
  germ-plasm, 389
  human, tendencies of, 411
  intellectual, 394
  main lines of, 393
  mechanism of, 417, 419
  mental, 335, 380
  neuromuscular system, 240
  of man, 387, 393, 394
  organic, 102, 417, 435
  past, causes and directions of, 386–397
  physical, 274, 288
  progress and retrogression, 305
  progressive, 415
  reversal of principle, 398
  social, 335
  societal, different from that in nature, 314
Exchange, media of, prehistoric, 299
Expedition, American Museum, 159, 184
Experimentalists, animal, 258
Experimentation, animal, difficulties of, 256–258
Experimentation, in relation to variations, 318
Expression, religious, 290
Extremities, phantasmal, 230
Eye, bar, *Drosophila*, 432
Eye, development, 196
Eyelid, vestigial, 220

Face, development of, 204
Factors, Darwinian, 308
  hereditary, 427
  individual, 386
Famine, 372
Farmers, foreign-born, 333
Fats, 85
Female, characteristics of, 244
Femur, development, 203
Fenno-Scandia, 289
Fertility, hereditary types, 441
Fertilization, 189, 190, 419, 422
Feudalism, 314
Finland, 348
Finn, 361
Fire, 366, 367, 368, 369
  introduction of, 365
  life derived from, 100
  taming of, 286
  use of, 364, 368
  users of, 370
  utilization of, 367
Fish, 295, 344
  forms, 117
Fishberg, 408
Fisher, Irving, 404
Fishes, 82, 90, 120, 124
  Age of, 46
  origin of, 66
  spawning instincts of, 256
Fishing, 372
Fitness, animal, 313
  in natural selection, 390
  societal, 313
Flame, kindling of, 365
Flesh, 295
Flight, true, evolution of, 129
Flint, chip, 286
  chipped, Eolithic Period, 280
  mining of, 293
Flints, Foxhall, 183, 184
  giant, of Cromer, 184
  rostro-carinate, 183
Flocks, domestic, 295
Floods, 344
Floras, origin of, 67
Flowers, heterozygous, 432
Fluctuation, climatic, 339
Fluctuations, 386
Flying dragons, 74
Food, 344, 346
  prehistoric, 294
Food supply, Neolithic, 294

Foot, pig, syndactylous, 435
  reptilian, 125
  terrestrial, evolution of, 124
  terrestrial, origin of, 112
Footprint, earliest known, 124, 145
Footprints, Connecticut Valley, 131
  Upper Triassic, 130
Foramen ovale, 208
Forchhammer, 275
Fore-brain, 193
Forefoot, polydactylous, cat, 434
  syndactylous, cat, 434
Forelimb, 274
Forest beds, pre-Glacial, 166
Formative era, 46, 48, 49, 50, 51
  earth-growth in, 48
  volcanism in, 49
Fossil man, Africa, 158
  Asia, 159
  Broken Hill mine, 159
  conditions of preservation, 154
  Crô-Magnon, 179–183
  Dallas, Texas, 157
  Dawn man, 167–170
  Heidelberg, 163–167
  Heidelberg, age, 166
  intelligence of, 262
  Lansing, 157
  Mousterian, 170–176
  Neandertal, 170–176
  Nebraska loess, 157
  Piltdown, 167–170
  Piltdown, age of, 170
  pre-Mousterian, 183
  Rancho La Brea, 157
  record of discovery, 156
  South American, 157
  Tertiary, 183
  Upper Paleolithic, 179
  Upper Pliocene, 184
  Vero, Florida, 157
Fossils, 60
  living, 82
Fowl, 295, 344
Foxhall flints, 183, 184
France, 340, 348, 352, 353, 354, 355, 357
Frank, T., 412
Franks, 340
Freedom of mind, 249
Frere, John, 283
Freres, 283
Frog, 261
  intelligence of, 259
Frontal, areas of brain, 268
Fruit fly, see *Drosophila*
Fruits, improved varieties, 429
Fuel, scarcity of, 345

Gabbro, 39
Gadow, H., 131
Galaxy, see Milky Way
Galley Hill skull, 183
Galton, 330, 399, 401, 403
Gams, 339
Ganoids, 123
Geikie, A., 77, 166
Gellivara, 345
Gene, 386, 425, 426, 427, 432, 435
  bar, 432, 433
  chromogen, 426
  lethal, 431
  mutant, 423, 424, 426, 429, 432, 433, 438
  mutation, 423
  normal allelomorphic, 431
  recessive, 424
Generation, spontaneous, 91, 92
Genes, 419, 420, 429, 430, 438, 440
  injury to, 437
Genetic change, 432
Genetic combinations, 439
Geneva, 382
Genial pit, 170
Genital organs, external, development of, 202
Geography, 276, 380
Geologic column, 61, 69

  history, 109
  record, 70
  time, eras of, 63
  time, length of, 81
  time, ratios of, 69
  time table, 46
eosynclines, 63, 64
erm cells, 389, 423, 430, 437, 440
  maturation, 431
  union, 190
erm plasm, 378, 386, 390, 395, 396, 403, 415, 417
  environment of, 388
  evolution in, 389
ermans, 301
ermany, 289, 340, 348
  champion of a code, 320
erminal inheritance, 389
ibbon, 140, 141, 142, 143, 145
ilFillan, 367
ill clefts, 197
ills, 121
irl, growth of, 215–216
lacial deposits, 55, 57
lacial Period, 46, 56, 338
lacial, times, post-, 381
laciation, 344
  of Europe, 338
  Wurm, 301
laciologists, 300
lasgow, 302
lass, 367
olgi bodies, 422
onads, development, 201
  grafting, 219
  migration, 202
  producing sex cells and hormones, 245
orilla, 140, 141, 143
oths, 340
overnment, a cultural adjustment, 312
  system of, 372
ower, Wales, 179
Graduates, college, children of, 403
Grains, origin of, 371
Grand Canyon revolution, 112, 119
Granite, 37, 40, 50, 76
Graphite, 65, 114
Grasses, expansion of, 137
  used for food by man, 144
Grasslands, of Asia, 375
  of North Africa, 375
Gravel beds, Hastings, 167
Gravels, Piltdown, 167
  Trenton, 157
Gravers, flint, 290
Gravitation, 98
Grazing mammals, expansion of, 138
  origin of, 112
  rise of, 137
Greece, 330
  decay of, 411
Gregory, W. K., 161, 163, 166, 170
Grimaldi, 182
  features of, 182
  relation to Bushmen, 182
Grotte de l'Observatoire, Monaco, 301
Grotte des Enfants, France, 182
Ground sloth, 158
Growth, 211
  bone, 215
  controlled by internal secretions, 212
  curves for height and weight, 215
  decreasing rate of, 212
  hereditary factor in, 212
  period of, 212
  relative rate of, in organs of body, 214
  retarded by certain factors, 214
Grypotherium, 158
Guinea pigs, gonad transplantation in, 244
Gunz-Mindel, 300

Habitats, organic, variability in, 79
Habits, fixed, 255
Haeckel, 248

Hair, development, 204
  fetal, 204, 225
  heredity of, 425
  regulation of development by hormones, 204
  slopes, 204
  tessellated junctions of, 204
Hairlessness, mice, 442
Haldane, 250
Hallstatt Epoch, 300
Hallstatt, village of, 282
Hampton Institute, 362
Hand, 274, 275
Hands, as organs of the mind, 144
Harelip, 205
Harpoons, 291, 292
Haughton, S., 70
Hazar Merd, cave at, 303
Heart, auricles, 199
  development, 198
  ventricles, 199
Height, average of, 217
Helix, of ear, 221
Helmholtz, H. L. F. von 10, 97, 99
Helmont, J. B. van, 91
Hematite, 298
Henderson, L. J., 89
Herds, 374
Hereditary mechanism, 419, 443
Hereditary units, 421
Heredity, 417
  Mendelian, 421, 422, 423
  Mendel's laws, 418, 430
Hermaphroditism, spurious, 201
Hernia, formation of, 201
Heterozygous, 431
  allelomorphic mate, 432
Hesiod, 283
Himalayan uplift, 147
Himalayas, 75
Hind, 292
Hind-brain, 193
History, natural, 277
Hittite Kings, 299
Holland, 289
Holmes, A., 53, 62
Homo (*Eoanthropus*) *dawsoni*, 143
Homo (*Paleanthropus*) *heidelbergensis*, 163–167
Homo neandertalensis, 170–176
Homo rhodesiensis, 176–178
Homo sapiens, 166, 179–184, 188, 280
  differentiation, 184
  Grimaldi type, 182
Homozygous, 431
  condition, 434
  sex, 426
Hopis, 342, 343, 372
Hormones, 198, 244, 389
  effect upon personality, 243
  of interstitial cells, 245
  relation to nervous system, 243
  see Internal secretion
Hornets, 91
Horses, 75, 137, 138, 292, 293, 343, 374
  breeding of, 440
  evolution of, 156, 212
Houses, adobe, 342
  block, Bronze Age, 295
Hoxne, Suffolk, 283
Hrdlicka, A., 157
Human intelligence, 262–270
Human mind, 379
Human race, present conditions and tendencies, 397–411
Humerus, containing supracondylar foramen, 225
  development, 203
Humidity, 348, 352, 353, 355, 360, 361, 362
Humors, 243
Huns, 340
Hunter, J., experiment of, 215
Hunters, nomadic, 343
Hunting, 341, 372
Huxley, T. H., 55, 108, 309, 388
Hybridization, 421, 439

Iybrids, 408, 439, 440
Iydrogen, 103, 247, 249
Iydrosphere, 51, 52, 56, 65, 76
Iyena, 292
Iylobates lar, 145
Iypophysis, see Pituitary body

ce Age, 277, 278, 279, 280, 288, 300, 301
  Permian, 52
  Proterozoic, 52
celanders, 337
deographs, 149
gneous rocks, 43, 76
  as source of oceanic salts, 57
  erosion of, 32
nagination, scientific, 107
npact, effects of, 28
nplements, Eolithic, 166, 170
  stone, 295
nbreeding, 439, 442
ndia, 338, 371
  Parsis of, 337
ndian, North American, 294, 341, 373
  of California, 341, 343, 344
  of Utah, 341
  Pueblo, 342, 344
ndo-China, amalgamation in, 408
ndustries, Magdalenian, 159
  new, 293
  pre-Crag, 183
  table of, 151
ndustry, ceramic, 293
  Eolithic, 286
  stone, 295
nferences, human, 269
nfusions, organic, 94
  sterilization of, 93
nfusoria, 347
ngenuity, Neolithic, 295
ngots, copper, traffic in, 299
nguinal canal, 201
nheritance, 417
  and variation, 385–388
  cultural, 364
  cytoplasmic, 422
  factors and mental capacity, 403
  germinal, 389
  mental, of dog, 379, 380
  paternal, 420
  racial, 339
  social, 320, 389
Insectivores, 137
Insects, 74, 90
Instinct and reason, 253
Instinctive, actions, theory of the origin of, 255
  manipulations, 267
Instincts, 254, 265
  animal, 255
  biological, utility of, 254
  hereditary, 254
Institute de Paléontologie Humaine, Paris, 302
Institutions, human, rise of, 316
Instruments, wooden, 295
Intellect, development of, 385
Intellectual power and cultural surroundings, 264
Intelligence, 270, 398
  and consciousness, 260–262
  and relation to nervous system, 267
  animal, 252–260
  evolutionary processes of, 260
  frog, 259
  function of nervous system, 252
  future development of, 270–273
  guinea pig, 259
  human, 262–270
  individual, field of, 267
  prehistoric man, 262
  primates, 259
  rudimentary power of, 260
  variation in human races, 263
Interaction, in inheritance, 423, 424
Interest and emotion, 324
Intermarriage, 402

Internal secretion, development of organs, 197
  influence of puberty, 217
  see Hormones
Interstitial cells, 245
Intervals, time, 72, 74
Intestine, appendix of, 221, 222
  cæcum of, 221, 222
Intussusception, 211
Invention, an adjustment, 312
  stimulus to, 366, 367, 368, 370
Inventions, great progress in, 396
Invertebrates, distinguished from vertebrates, 115
  evolution of, 115
IPEK, 302
Iraq, 303
Iron, 283, 344, 345, 383
  compounds of, 103
  discovery of use, 375
  first used, 299
Iron Age, 159, 276, 285, 299, 302
Iron tools, 376
Irrationalism, 395
Irrigation, effect of, 371
  importance of, 371
Irritability, of living matter, 96
"Ishmaels," 400
Isolation, from ancestral stock, 439
  geographical, lack of, 407
  racial, 406
Isostasy, 40, 41
Italy, 348, 352, 353, 354, 355, 357, 360

Jacob's cavern, 158
Jahrbuch für Prähistorische und Ethnographische Kunst, IPEK, 302
Jamestown, deaths, 335
Japan, 348, 357, 360
Jaw, Heidelberg man, 163
  shrinkage of, 223
Jefferson, Thomas, 75
Jelly-fishes, 115
Jews, amalgamation of, 408
Johnston and Williamson, 53
"Jukes," 400
Jupiter, 5, 6, 31
Jurassic, Lower, 146
  period, 46, 77, 80, 112, 131, 13
  Upper, 128, 130, 146
Juvenile waters, 38, 76

Kaa, 257
"Kalikaks," 400
Kankakee uplift, 64
Kant, hypothesis of, concerning evolution of solar system, 10
Keith, Sir A., 157, 158, 165, 168, 169
  173, 175, 179, 183, 184
Kelvin, 97
Kentucky, 360
Kesslerloch, 284
Key, iron, La Téne Epoch, 300
Kings, Hittite, 299
Kircher, 91
Knitting, 295
Knives, scraper-, 289
Krapina, Austria, 172
Kuhn, Herbert, 302
Kultur, 391

La Chapelle-aux-Saints, France, 172
La Ferrassie, France, 172
La Naulette, Belgium, 172
La Quina, France, 172
La Tène Epoch, 300
La Tour, C. de, 94
Labor, division of, a mores, 315
Labrador, 278, 341
Lamprey, 117
Land-bridges, 74, 75, 139
Land waters, as place of chordat
  origin, 120
Lands, contributions of, to oceans, 6
  elevation of, 71, 110, 111, 112
  Mediterranean, 382
Lane's law, 15

Language, 266
  a mores, 315
  advantage of, to man, 266
  as a mores, 319
  man's control over, 268
  responsible for man's superiority, 268
Lanugo, 225
Laplace, P. S. de, 10, 51
Laramide revolution, 112, 133, 135, 146
Lartet, Edouard, 283, 284
Lastic, Vicomte de, 284
Latin Europeans, 362
Laurentian peneplain, 119
Lava, 2, 38, 44, 76
Lavas, of moon, 43
  Proterozoic, 65
Law of Complexity, 102
Lawn-mowers, power, 368
Le Moustier, France, 171
League of Nations, 306
Lehman, 361
Leith and Mead, 62
Lepidosiren, 123
Lethal characters, 426
Levalloisian, 301
Leverrier, U. J. J., 27
Lewes, 87
Lias, climate of, 56
Life, 89
  ancient, 60
  Archeozoic, 65
  as manifestation of protoplasmic activity, 83
  changes in, 74
  chemical elements, 106
  communal, 145
  cycles in, 74
  definitions of, 86
  dormant, 98
  elements, 106
  elements, in colloidal suspension, 107
  fresh-water, record of, 60
  land record of, 60
  marine, increase in, 79
  marine, record of, 60
  materials at basis of, 52
  origin of, 65, 83, 95, 113
  paleontological record of, 94
  pulse of, 82, 110, 112, 145, 147
  scientific explanation of, 96
  thermometers, 56
  transportation of, through space, 97
  vehicle of manifestations of, 86
Life-conditions, 311
Life cycle, 218
Light, radiation pressure of, 98
Lightfoot, John, 148, 149
Lightning, 103, 104
Limbs, change in, in primates, 144
  development, 203
  pentadactyl, 203
Lime-secretion, establishment of, 114
Limestones, 59, 61 62, 66, 67, 69, 70
Lion, 292
Lithosphere, 41, 50, 51, 76, 77
  density differences in, 41
Liver, development, 198
Lizards, 131
L'Observatoire, Monaco, 301
Locusts, 91
Loeb, J., 99
Loligo, 116
London, 278, 283, 382
Longperier, curator, 284
Los Angeles, 342
Louvre, 284
Lucretius, 90, 283
Lull, R. S., 331
Lung-breathing, first recorded, 124
  place of origin of, 122
Lung-fishes, 122, 123
  first recorded, 124
Lungs, development of, 145, 197
  of higher vertebrates, 121
  origin of, 112

Magdalenian, 300, 303
Maggots, 91
Magmas, 2, 34, 37, 38, 39, 40, 42, 43, 44
Male, characteristics of, 244
Mammalia, Pleistocene, 160
Mammals, 67, 74, 82
  Age of, 46
  archaic, 112, 135, 136, 137, 146
  browsing, origin of, 112
  evolution of, 128, 146
  expansion of, 135
  fate of, 136
  first recorded, 112, 128
  grazing, rise of, 112, 137, 138
  instincts of, 256
  modernized, 136, 146
  modernized, origin of, 112
  modernized, source of, 136
  origin of, 112, 129, 146
  placental, 127
  rise of, 134
Mammary glands, supernumerary, 225
Mammoth, 292
Man, ability to accustom to different environments, 311
  Age of, 46
  American, 188
  and anthropoids, 309
  behavior of, 268
  bodily evolution of, 395
  brute-, 75
  Caucasian, 188
  Committee on Atmosphere and, 357
  controlling his evolution, 398
  dispersal of, 153
  dominance of, over organic world, 145, 147
  Ethiopian, 188
  evolution of, 387
  fossil, see Fossil man
  Java, see *Pithecanthropus*
  Malay, 188
  Mongolian, 188
  Mongoloid, 158
  Neandertal, 161, 170–176
  Neolithic, 293, 296
  nervous system of, 232
  nervous system, summary of evolution in, 250
  New World, 158
  normal life cycle, 220
  origin of, 112, 138
  Paleolithic, 293
  phylogeny, 185
  polydactyly, 436
  prehistoric, 277, 293, 298
  prehistoric, species, 160
  primitive, 367
  primitive, language of, 266
  progressive, evolution of, 393–397
  races of, 186, 188
  reasoning, 75
  rise of, 147
  similarity of, 310
  structural relations, 186
  structural unit of, 186
Manipulations, instinctive, 267
Mankind, birthplace of, 152
Mantle, 194
Marks, of students, 356
Marriage, 314, 325, 336
  a cultural adjustment, 312
  hindered by modern conditions, 391
  productivity of, 391
Mars, 5, 27, 31
Marshall, Alfred, 410
Maryland, 360
Mas d' Azil, 292
Massat, cave of, 284
Mastodon, engraving of, 158
  remains of, 158
Mate selection, 401
Mating, assortative, 401
Matter, complexification in, 101
  evolution of, 107
  living, irritability of, 96
Maturation, 419, 440

Mauer, Germany, 163
  sands, 163, 164
Maupas, theory of, 220
McGregor, J. H., 162, 163, 164, 166, 168, 169, 173, 174, 180
Mechanism, neuromuscular, 233
Mechanism, hereditary, 419, 423, 435
  heredity, 424
  sex-determining, 426
Mediterranean, 335, 338, 339, 345, 357, 361
"Melting pot," 409
  Roman Empire, 412
Membranes, extra-embryonal, 127, 129
Men, Stone Age, 286
Mendel, 283, 418, 430
Mendelian combinations, 386, 387, 402, 429
Mendelian heredity, 418, 421, 422, 423
  inheritance, 409
  ratio, 432
Mendelism, 386, 418
Menhirs, 299
Mental life, various factors which influence, 272
Mentality, 82
Mercury, 28
Mesoderm, 191
Mesolithic Culture, 292
Mesolithic Peoples, 293
Mesolithic Period, 293, 294
Mesopotamia, 277, 338, 371, 383
Mesozoic era, 46, 67, 74, 77, 79, 80, 112, 133, 134
  time ratio of, 69
  sediments, thickness of, 69
Metabolism, of body, 347
Metacarpals, of mammoth, 294
Metals, 296, 364
Metals, Age of, 298, 301
  art of extracting, 298
  discovery of, 299
Metazoa, 187
Metchnikoff, theory of, 219
Meteorites, 33
Meteors, 27, 98
Mexico, racial amalgamation in, 408
Miacidæ, 137
Mice, 91, 442
  hairlessness, 442
  Peromyscus, 441
Microcosm, organism as, 89
Microlithic, 303
Mid-brain, 193
Middens, kitchen, 293
Migrants, 336, 339, 370, 375
Migration, 337, 369
  effects, 340
  hardships of, 370
  prehistoric current, 303
  selective power of, 338
Migrations, 335, 340, 382, 383
Milky Way, 8
Miller, G. S., Jr., 168
Mind, human, 379
Mindel-Riss, 300
Miners, coal, 345
Mining, 343
  Neolithic, 295
Minot, on differentiation, 393
  theory of, 220
Miocene time, 46, 112, 137, 139
  aridity in, 144, 147
  diastrophism in, 143, 147
Mississipian period, 46, 77, 80, 112, 126, 146
  aridity in, 146
  diastrophism in, 126
Mitochondria, 422
Mitosis, 427, 428
Mohammed, 340
Mohawkian period, 77
Moir, 300
Molecules, 85, 101
Molluscs, 115, 121
Molten stage, in earth's history, 26, 33

Momsen, 411
Monaco, L'Observatoire, 301
Mongoloid, 361
Monotremes, 128
Monuments, megalithic, 298
Mood, mental, 346
Moon, 2, 5, 13, 28, 30, 33, 43
  effect of earth on, 30
  effect of, on earth, 28
  in Archeozoic, 65
Moon-knot, 48
Moore, B., 101
Moulton, F. R., 12, 18, 19, 47
Mountain-making, 54, 71, 79, 110
Mountains, 72
  origin of, 49
Moravia, prehistoric food, 294
Mores, 315, 316, 317
  and education, 320
  and imitation, 319
  and life conditions, 316
  and sex, 316
  code of behavior, 325
  learned not inherited, 319
  transmitted by tradition, 319
Morgan, T. H., 387, 425
Morula, 190
Mousterian Epoch, 300
Mousterian industries, 150, 151
Mousterian races, 286
Mousterian stage, 288, 289
Mowgli, 257
Muds, 59, 62
Mud-skippers, 121
Mudstones, 58, 59, 61, 62, 67, 68, 69, 70
Mulattoes, 408
Mules, chromosomal distribution, 441
  sterility in, 440
Muller, 437
Murals, cavern, 159
Muscle, *rectus*, 224
  sternalis, 224
  subtegumentary, 224
Muscles, development, 201
  effectors, 233
  shifting of position, 203
  vestigial, 221
Mutant characters, 430
Mutant type, 429
Mutants, 331
Mutation, 424, 426, 431, 436
  bud, 429
  cause of, 435
  direction of, 431
  dominant, 435
  effects of, 430
  gene, 423, 431
  lethal, 430
  lethal, sex-linked, 431
  mosaic, 429
  non-disjunction, 427
  physiological, 430
  progressive, 432
  regressive, 432
  semi-lethal, 430
  structural, 430
  syndactylous, 435
  time and place of, 431
  twinning, 434
Mutation and Evolution, 430
Mutations, 380, 386, 387, 418, 419, 439, 441, 443
  accumulated, 440
  and environment, 388
  corn, 437, 438
  experimental production of, 436
  directions of, 391
  recessive, 442
  recombinations of, 429
  speeding up, 437
  survival of, 443
  their causes, 388
  types of, 423
  unsuitable, 436
Myelin sheath, 195
Myotomes, 192
"Myth," Nordic, 335

"Nams," 400
Naples, 278
Nasal cavity, development of, 205
Natural law, 325
Natural sciences, future achievements in, 271
Natural selection, 135, 158, 178, 313, 390, 410
  elimination of the unfit, 321, 398
Naturalists, observations of, 256–258
Nature, uniformity of, 47
Neandertal man, features, 170–176
  ideas concerning, 175
  modern representatives of, 176
  skeleton, 172, 173
Neandertal race, 286
Neandertal stage, 288, 289
Nebulæ, 8
  irregular, 8
  planetary, 8
  ring, 9
  solar, 21, 48
  spiral, 8, 9, 13, 18, 20, 21, 48
  stellar, 9
Nebular hypothesis of Laplace, 10
  hypothesis of Laplace, modifications of, 11
Needham, T., 93
Negative areas, in earth's surface, 51
Negroes, 334, 361, 362
Neoceratodus, 122, 123
Neogene time, 80
Neolithic Age, 302
Neolithic chronology, 301
Neolithic culture, 293
Neolithic food supply, 294
Neolithic ingenuity, 295
Neolithic man, 293, 296
Neolithic mining, 295
Neolithic Period, 149, 295, 296, 298
Neolithic races, 298
Neopaleozoic time, 80
Neopallium, 194, 241
Neptune, 4, 5, 6
Nerve cells, 194
  development, 197
  evolution, 197
  number in cortex, 241
  see Neurones
Nerves, afferent, 197
  motor, 194
  myelin sheath, 195
  sensory, 194
Nervous elements, lacking in sponges, 240
Nervous organization, sea-anemones, 234
Nervous system, adjustors, 232, 234
  and organization, 247
  and personality, 229–231
  and sex, 242–247
  central, 232, 234
  diffuse, 235
  earthworm, 233
  effect of interstitial secretions, 246
  effectors, 233
  in relation to intelligence, 252
  influenced by environment, 243
  intricate structure of, 232
  man and higher animals, 232
  organization, 232
  receptors, 233
  reflex mechanism, 195
  rudiment, 192
  summary of evolution in man, 250
  sympathetic, 233
  vertebrates, 241
Neural groove, 192
  tube, 192
Neuromuscular mechanism, 233
Neuromuscular system, evolution of, 240
Neurones, 194
  internuncial, 232
  motor or efferent, 232, 233
  see Nerve cells
  sensory or afferent, 232, 233

Neutral medial area of North America, 64
Newfoundland, northern, 341
New Mexico, 341
New World, 286
New York, 278, 354
New York City, 360
  deaths in, 356, 357
New Zealand, mixed races, 410
  vigor of, 340
Nilsson, 275
Nitrogen, 44, 103, 104, 247
  compounds, 105, 106
  in primordial atmosphere, 34
Nodosaurs, 133
Nome land-bridge, 75
Non-disjunction, 427
Nordhagen, 339
Nordic, 361
Nordic "myth," 335
Norsemen, 340
North America, 278
  in Paleozoic time, map of, 64
North Carolina, 360
North Pole, 278
Nose, development, 205
Notochord, 192
Nourishment of embryo, prenatal, 205
Nuclei, planetary, 19, 33
Nucleus, 419
Nythosaurus larvatus, 129

Obercassel, Germany, 181
Objects, bronze, art of casting, 298
Occupation, human, 370
Oceanic basins, 43
  currents, 55
  currents, changes in, 74
  floodings, 63, 72, 76, 77, 80
  floodings, Cretaceous, 78
  floodings, Pennsylvanian, 68
  floodings, Silurian, 73
  in Archeozoic, 65
  increase in volume of, 39
  level, inconstancy of, 77
  origin of, 39, 50
  relations of crustal density to, 39
  salts, 31, 51, 57
  waters, gathering of, 37
  waters, increase in volume of, 51
  waters, origin of, 56
Oceans, carbon dioxide in, 53
  increase in area of, 79
  origin of, 37
  when smallest, 74
Offspring, hybrid, 440
Old World, 278, 282, 286
  prehistory, 302, 303
Oldoway ravine, 158
Olfactory, archipallium, 241
  cortex, 241
  organ, development of, 205
  organ, retrogression in, 221
  pits, 205
Oligocene time, 46, 111, 112, 135, 136, 137, 145, 146
Ontogeny, 200, 396
  course of, 391
Orang, 140, 141, 143
Orbits, planetary, 5, 19
Ordovician period, 46, 80, 112, 114, 120, 145
Ore, 375
Organic deposits, 59
  habitats, areal variability in, 79
Organicism, 250
Organism, 106
Organisms, bionomic relations of, 109
  individuality of, 88
  origin of, 107
  structural unit of, 187
Organization, 312
  and a society, analogy between, 307
  in relation to nervous system, 247–249
  nervous, of sea-anemones, 234
  sponges, 238–239

Organs of body, relative rate of growth, 214
Orient, 339
Orion, 8
Orthogenesis, 388
Osborn, H. F., 105, 163, 166, 181, 182, 183
Ouse, Sussex, 167
Ovum, fertilization, 189, 191
  structure, 190
Ostracoderms, 120
  origin of, 112
Oven, mud, China, 366
Over-specialization, indications of, 132
Ox, 374
  beasts of burden, 294
Oxalates, 108
Oxides, 101
Oxygen, 44, 52, 103, 347
  importance of, for life, 93
  in primordial atmosphere, 34
Ozark uplift, 64

Pacific Islands, racial amalgamation in, 408
Paleogene time, 80
Paleogeography, 68, 73, 78
Paleolithic, 46, 151, 285, 303
Paleolithic art, 291
Paleolithic man, 293
Paleolithic period, 149, 290, 292
Paleozoic era, 46, 66, 67, 77, 79, 80, 112, 128
  North America in, 64
  sediments, thickness of, 66, 69
  time ratio of, 69
Palestine, 303
Pallium, 194
Pan vetus, 168
Panama land-bridge, 75
Pancreas, development, 199
Parables, 307
Parathyroid gland, development, 197
Paris, 382
Paris, *Institute de Paléontologie Humaine*, 302
Parr, Thomas, 218
Parsis, of India, 337
Particles, protoplasmic, 384
Past, prehistoric, 282
Pasteur, L., 94
Pathways, hereditary, 254
Patten, W., 120
Peabody Museum of Yale University, 124, 134
Pearl, R., 406, 407, 410
Pech de l'Azé, France, 171
Pedersen, 361
Peneplanation, 77
Pennsylvanian period, 46, 68, 77, 80, 112, 128
  diastrophism in, 128, 146
  North America in, 68
People, non-Nordic, 335
  Pueblo, 342
Peoples, Mesolithic, 293
Perception, sense, 264
Pericles, age of, 331
Period, Glacial, 338
  historic, 339
  Lower Paleolithic, 286
  Mesolithic, 293, 294
  Middle Paleolithic, 287
  Neolithic, 296, 298
  Paleolithic, 282, 285, 290, 292
  Quarternary, 279, 288
  Tertiary, 279, 286, 288
Periodicity, 71, 76
Periods, prehistoric, chart of, 285
Periophthalmus, 121
Permian period, 46, 77, 80, 111, 128
  aridity in, 146
  climate of, 52, 56, 128, 130, 146
Peromyscus, 441
Personality, and nervous system, 229–232
  influence of sex glands upon, 247

Perthes, Boucher de, 283, 284
Petromyzon, 117
Pflüger, E., 100
Phantasms, 323
Phasic activity, 101
Phenacodus primævus, 137
Phosphates, 108
Phylogeny, 200, 396
  course of, 391
  provisional, of man and anthropoids, 185
Pig, 373, 374
  mule-footed, 434
Pile village, home life of, 296
Pile villages, 295
Pineville, Missouri, 158
Pithecanthropus erectus, 160–163
Pituitary body, development, 197
Placenta, development, 206
  filter against bacteria, 207
  intervillous spaces, 206
  osmosis in, 206
  passage of materials through, 206–208
  separation of fetal and maternal blood, 206
  villi, 206
Planetary nuclei, 19, 33
  system, 48
Planetesimal dust, 25
Planetesimal hypothesis, 13, 102
  outstandnig difficulties of, 20
  material, 32
Planetesimals, 35, 48
  earth-growth by slow accretion of, 24
Planetoids, 4, 5, 26, 28
  earth-growth by rapid infall of, 25
  significance of, 26
Planets, 4, 5, 13, 18, 19, 24, 28, 31
  relations of, 5, 6
Planning, stimulation of, 372
Plants, 347
  flowering, 67, 74
  herbaceous, 137
  lime-secreting, 114
Plastids, 422
Pleiades, 8
Pleistocene, 155, 157, 165, 170, 184
Pleistocene time, 46, 112, 139
  climate of, 56, 68, 111
Plica semilunaris, 221
Pliocene, 163, 166, 183, 184
Pliocene time, 46, 112
  aridity in, 144
Plows, iron, 377
Plymouth, deaths, 335
Poisons, protoplasmic, 436
Polydactylism, 203
Polydactyly, man, 436
Polypterus delhezi, 123
Population, agricultural, 377
  and subsistence, 410
  Bronze Age, 298
  effect, of the world, 410
  foreign-born, birth-rate, 406
  limits of, 410–411
  maximum, 410
  native birth-rate, 406
  negro, of United States, 408
  of given area, 336
  South American countries, 408
  United States, 410
Positive areas, in earth's surface, 51
  in North America, 64
Postnatal retardation, 216
Posture, erect, assumption of, 144
Pottery, 293
  making of, 365, 367
  prehistoric, from Marne, 300
Pre-Chellean, 300
Pre-Columbian, 341
Prehistoric Research, American School of, 303
Prehistory, 275, 276, 277
  Europe, 278, 302

  European, 302
  European problems, 300
  Old World, 302, 303
Prepubertal acceleration, 217
Primary germ layers, 191
Primates, 137, 138, 144
  American, 138
  descent of, from trees, 144, 147
  distribution of, 139, 140
  Eocene, 138
  European, 139
  evolution of, 147
  origin of, 112
  radiation of, 138, 139, 143
Primitive streak, 191
Proavian, 130
Problems, present, in prehistory, 300
Proboscidea, 75, 137
Process, selective, 337
Processes, evolutionary, 280
  rational, 259
  selective, 321, 370
Products, cultural, 312
Progress, course of human, 367
  human, 364, 377
  human, factors in, 330
  stimulus to, 368
Progress and evolution, 305
  due to specialization and coöperation, 392
  definition of, 391, 392
  limits of, 392, 393
Pronation, 274
Propagation, by selection, 402
Proportions of body, changes in during life, 213
Proteins, 85, 86, 100, 101
Proterozoic era, 46, 114, 119, 145
  climates of, 52, 56
  lavas, 65
  sediments, thickness of, 65, 69
  time ratio of, 69
Protestantism, 322
Protochordates, 119
Protoplasm, 83, 89, 100, 101, 106
  alveolar substance of, 84
  chemical characteristics of, 85
  combinations of elements in, 85
  lability of, 86
  living, evolution of, 108
  physical characteristics of, 84
  primeval, 330
  variation in, 88
Protopterus, 122
Protozoa, 97, 98, 114, 187
Psychozoic era, 46, 68
Puberty, 217
  influenced by internal secretion, 217
Pueblo Indians, 342, 344
Pueblo Indians, diet of, 342
Pueblo people, 342
Pulsations, climatic, 339, 381
Pulse of life, 82, 110, 112, 145, 146
Puritan, 337
Pygmies, 152
Pyrenees, 292

Quaternary Period, 151, 288

Rabl, C., 124
Race, composite, characteristics of, 409
  differentiation and amalgamation, 406–410
  mixtures, 407
Race suicide, 313
  Roman Empire, 412
Races, blending of, 408
  difference in intelligence, 263
  mixture of, 339
  Neolithic, 298
  primary, of mankind, 408
  Upper Paleolithic Crô-Magnon, 287
  white, 362
Racial isolation, 406
Radio, 368
Radioactive elements, 42
  minerals, rate of disintegration of,

    - as basis for computing geologic time, 69, 70
- Radiolaria, 114
- Radium, emanations, 431, 436
- Rain, 55
  - first, on earth, 37
- Raisers, of cattle, 374
- *Ranodon sibericus*, 125
- Ratio, Mendelian, 432
- Rational, conduct, 253
  - processes, 259
- Reactions, adaptive, 261
  - animal, acquiring of, 269
  - reflex, 254
  - spontaneous, 255
  - summary of, in various animals, 259
  - tropistic, 261
- *Reallexikon der Vorgeschichte*, 302
- Realm, societal, elemental forces in, 327
- Reason and instinct, 253
- Recapitulation, Law of, 200
- Receptors, 233
  - sea-anemone, 237
- Recombinations, 386
  - chromosomal, 430
- Recrystallization, 40
- Redi, F., 91, 92, 93
- Reflex actions, 254
  - theory of the origin of, 255
- Regeneration, in amphibia, 213
  - in man, 213
  - power of, 213
- Region, polar, 278
  - Pueblo, 343
- Regions, irrigated, 372
- Reindeer, 292, 341
- Rejuvenescence, 219
- Relation, physical, of man, 347
- Religion, 314, 325
  - evolution of, 271
- Remains, cultural, 281
- Reproductive system, development, 201
- Reptiles, 67, 74, 82, 133, 146
  - Age of, 46
  - foot of, 125
  - origin of, 67, 112, 126
- Research, Prehistoric, American School of, 302, 303
- Resources, agricultural, 342
  - material, 340, 341, 344, 345, 364, 378
- Response, climatic, 361
- Retardation, postnatal, 216
- Retrogression, 221–223
- Revolutions, 72
- Rhinoceros, woolly, 292
- Rhinoceroses, 137
- Rhodesia, Broken Hill mine, 159, 176
- Rhodesian man, 176–178
  - skull, 178
- Rhythms, in solar energy, 110
- Ribs, variation in number, 223
- Richter, 97, 99
- Riss-Wurm Epoch, 151, 300, 301
- Riss Glacial Epoch, 151, 301
- Rivers, 55, 58, 77
- Rocks, acidic, 50
  - basaltic, 50
  - basic, 50
  - granitic, 50
  - sedimentary, 58, 63, 69, 70
  - stratified, composition of, 62
- Rodents, 137
- Roman Empire, race suicide, 412
- Rome, decay of, 411
- Ross, 91
- Rubner, 220
- Russia, 289

- Sacramento, deaths in, 158, 161
- Saint-Acheul, 282
- Salamander, foot of, 125
- Salt, 299, 344
  - deposits, 32
  - oceanic, derivation of, 32
  - oceanic, significance of, 31
- Salt Lake City, 342

Salzkammergut, Austrian, 282
San Francisco, 355
Sandstones, 59, 62, 69, 70
Santa Fe, 342
Satellites, 6, 19
Saturn, 5, 6, 31
Sauropoda, 112, 131, 133, 146
  characteristics of, 132
Sautuola, 283
Savagery, 342
Saxons, 340
Scandinavia, 286, 340
Scandinavians, 301
Schäfer, E. A., 99
Schoetensack, Dr. O., 163, 166
Schuchert, C., 111
Schwann, 94
Science, Advancement of, British Association, 302
  discovery of, 346
Science and religion, 322
Scorpions, 91
Scraper, well-formed, 287
Scraper-knives, 289
Scrapers, flint, 287
Sea-anemone, 115
  creeping, 236
  effect of stimulation, 234
  effectors, 237
  feeding of, 235, 236
  nervous organization, 234
  receptors, 237
  sense organs, 238
  structure, 234
  tentacle, effect of detaching, 235
Secretions, 347
  interstitial, effect on nervous system, 247
Sedimentary rocks, distribution of, 63
  rocks, origin of, 58
  rocks, thicknesses of, 63, 69, 70
Seeds, 98
  wild, gathering of, 372
Segments, 192
Segregation, 380, 402, 430
Selection, 308, 321
  a negative process, 321
  essential processes of, 321
  natural, 107, 331
  ordinary, improvement by, 326
  social, 331
Selenka, Madame, 160
Self-direction, 324
Self-maintenance, 315
Senescence, 218–220
  theories of, 219
Senile degeneration, see Senescence
Sensation, 230
Sensations, primitive, 249
Sense organs, retrogressive changes in, 221
  sea-anemone, 238
Sense perception, 264
Sensorium commune, 229
Series, multiple allelomorphic, 426
Sex and nervous system, 242–247
Sex, cause of, 210
  center of society, 246
  conditions, indifferent, 201
  definition of, 243
  determination before birth, 211
  glands, see Gonads
  homozygous, 426
  reversal of, by gonad transplantation, 244
  transformation of, 244
Sex-determining mechanism, 426
Sex-linked characters, 426
Sextuplets, 210
Sexual characteristics, determined by gonad, 245
  primary, 244
  secondary, 244, 245
  secondary, controlled by gonad, 244
Sharks, 121
Sheep, 374
Shellfish, 91, 294
Shell-heaps, 293

Shelter, 346
  discoveries, 365
Shere Khan, 257
Ships, votive, 299
Sickness, amount of, 347
Silica, 101
Silurian period, 46, 77, 80, 112, 123, 124
  climate of, 56
  diastrophism in, 123, 145
  North America in, 73
Sites, prehistoric, 282
Skeleton, cartilage, 203
  development, 203
  foot, pig, 435
  membrane, 203
Skin, development, 204
Skull, Calaveras, 156
  cap, *Pithecanthropus*, 160, 161
  Gibraltar, 171
  pre-Neandertal, 166
Slavery, an adjustment, 306
  human, 294
Sloths, fossil, 75
Smelting, discovery of, 376
Smith, Elliot, 168
Snails, 91
Snow, 55
"Social theory," 329
Societal, adjustment, 314
  code, 317
  evolution, past processes, 381
  fitness, 313
  range, forces at work, 328
  realm, 327
  selection, in relation to war, 322
  selection, various forms taken by, 323
Societies, struggle of, 321
Society, and organisms, analogy between, 307
  human, changes in, 395
  relation of, to sex, 247
  stratification of, 402
  systems, cultural adjustments, 312
Socrates, 340
Soil, 335, 344
Solar energy, 103
  energy, rhythms in, 110
  prominences, 16
  system, elements of, 5
  system, Kant's hypothesis of evolution of, 10
  system, Laplace's theory of origin of, 10
  system, plantesimal hypothesis of origin of, 13
Sollas, W. J., 159, 182
Solutrean, 300, 303
Space, interstellar, transportation of life through, 97
Spallanzani, L., 93
Specialization, and progress, 392
  relation to regeneration, 213
Species, crossing, 439
Speech, acquisition of, 286
Sperm, 424
Sperm cells, 243, 420, 437
  in fertilization, 190
  structure, 190
Spider, instincts of, 256
Spindle, mitotic, 427
Spinning, 295
Sponges, 114, 115, 238–240
  lack of nervous tissue, 240
Spontaneous generation, 91, 92
Spores, 97, 98, 99
Spy, Belgium, 171
Squids, 74, 115, 116
Stage, hunter, of civilization, 290
  Mousterian, 151, 285, 288, 289
  Neandertal, 151, 288, 289
  tree-dwelling, 288
Star streams, 7
Stars, 6, 13, 15, 23
  chances of close approach among, 22
  mode of tidal disruption in, 15
  new, 9

- Wolf-Rayet, 9
- Static forms, 82
- Stations, Aurignacian, 303
- Steel, Age of, 300
- Stefansson, 367
- Stegocephalia, 126, 146
- Stegosauria, 131, 133
  - characteristics of, 132
- *Stegosaurus*, 131
- Steinach, 219, 245, 246
  - gonad transplantation, 244
- Stellar system, sun a member of, 6
- Sterility, 437, 439, 440
  - mules, 440
- Stimulation, effect of, in sea-anemones, 235
- Stockholm, 354, 360, 382
- Stone, Age of, 150
- Stone Age, 276, 285, 296
  - men of, 286
  - New, 275
  - New, chronology of, 301
  - Old, 275, 281, 300
- Stoves, metal, of Europe, 366
- Strand-line, 77, 121
- Stratification, density, 36
- Struggle for existence, 74, 82
- Sub-species, mice, 441
- Suess, E., 38
- Sulaimani, 303
- Sulphur, 103
- Sumatra, 188
- Sumner, W. G., 315, 317
- Sun, 4, 10, 12, 13, 19, 20, 44, 99, 106
  - ancestral, tidal disruption of, 16
  - as life factor, 55
  - as member of stellar system, 6
  - critical velocity of, 17
  - origin of, 47
  - prominences shot out from, 16
  - rotation of, 20
- Sunshine, 103
- Superstition, 395
- Supination, 274
- Supracondylar foramen, 225
- Surface processes, in earth, 43
- Survival of the fittest, 321
- Swan, 90
- Sweden, 345, 348, 357
- Swim-bladder, 121
- Swine, 137
- Swiss, 301
- Switzerland, 278, 289
  - lowlands of, 339
  - prehistoric food, 294
- Sympathetic system, 233
- Synapsis, 441
  - chromosomes, 440

- Tail, in man, 225
- Talismans, 296
- Tapirs, 137
- Tardenoisian, 303
- Tariff, protective, 306
- Tartrates, 108
- Tasmanians, 150
- Teeth, cynodont, 161
  - decay, 223
  - dentine, 205
  - development, 205
  - enamel, 205
  - first set, 215
  - fourth molar, 224
  - Heidelberg man, 165
  - permanent, 215
  - pulp, 205
  - retrogressive changes, 222
  - taurodont, 161
- Temperature, 348, 355, 357, 360, 361, 362
  - mean, 352, 353
  - range of, 353
  - rise of, 356
  - variations of, 356
- Tendency, tropistic, 254
- Tentacle, sea-anemone, 235
- Terrestrial foot, evolution of, 124

  origin of, 112
  types, influence of aridity on, 128
Terrestrial types, influence of increasing cold on, 128
Terrestrial vertebrates, eggs of, 127
  emergence of, 120, 123
  waters, as place of chordate origin, 120
  as place of origin of lung-breathers, 122
Tertiary, climatic oscillation in, 136
Tests, psychological, American Army, 265
Tetraprothomo, 157
Thames gravels, 183
Theriodonts, 129
Thermal springs, 57, 76
Theropoda, 131
Thinopus antiquus, 124, 125
Thomsen, C. J., 275, 276
Thorium, 42
Thymus glands, development, 197
  fate of, 198
  migration, 198
Thyroid glands, development, 197
  migration, 198
Tidal disruption, forces of, 13, 14
  force, of earth on moon, 30
  in ancestral sun, 16, 17
  mode of, in stars, 15
  retardations, 28
  strains, in earth, 30
Tide-generating force, 16
Tides, body, 29
  in Archeozoic, 65
  loss of energy due to, 29
Time, prehistoric, 276
  prehistoric, measuring, 281
Time Table, geological, 46
Times, Neolithic, 295
  post glacial, 381
Tinstone, 298
Tools, artificial, 286
  invention of, 364
  iron, 343, 367, 376
  natural, 286, 289
  not used by lower animals, 266
  prehistoric, 281
  primary, 286
  secondary, 286, 287, 288, 289
  tertiary, 290
Trachodons, 133
Transmission, of mores by tradition, 319
Transplantation, gonad, 244
Transportation, 383
Trephining, 296
"Trial and error," 390
Triassic period, 46, 77, 80, 112
  climate of, 56
  Upper, 128, 130, 134, 146
Trinil, Java, 159, 160
Triton, 125, 126
Troland, L. T., enzyme theory of, 104
Tropics, 371
Tropisms, 253, 254
Trumpet, bronze, 297
Tubercle, of ear, 221
Tübingen, *Urgeschichtliches Forschungsinstitut*, 302
Tunicates, 118
Tyndall, J., 94
Type, mutant, 429
Tyrol, 289

Underhill, F. P., 85
Ungulates, 137
Uniformitarian trend, of biologic thought, 107
United States, 348, 352, 353, 354, 355, 357, 360, 376
  colored people in, 354
  vigor of, 340
Upper Boulder Clay, 301
Uranium, 42, 69
Uranus, 4, 5, 6, 31
Urgeschichtliches Forschungsinstitut, Tübingen, 302

Urinary system, development in relation to genital system, 201
Utah, 343, 344
  Indians of, 341
Uterus, contractions at birth, 208
  digestion of wall by embryonic cells, 206
Utes, 342, 343, 34

Valley, Vezere, 284
Vandals, 340
Variability, interdiurnal, 357
  of any region, 362
Variation, 308, 317
  accidental, in relation to reflexes, 255
  anatomical, 223–225
  and experimentation, 318
  and inheritance, 386–388
  and the world-code, 320
  depend upon verification, 318
  environmental, 386
  rational, 318
Vas deferens, 219
Vascular system, development, 199
Vegetation, 344
Veins, development, 201
Ventricles, 199
Venus, 5, 28
Vermiform appendix, 221, 222
Vertebral column, 192
Vertebrates, distinguished from invertebrates, 115
  egg of, change in, 127
  evolution of, 114
  first recorded, 145
  origin of, 112, 115, 145
  terrestrial, emergence of, 120, 123
Vestigial structures, 220–223
Vezere, valley of, 284
Vicomte de Lastic, 284
Vienna, 382
Villages, Neolithic, 298
  pile, 295
  pile, Bronze Age, 298
  pile, of Switzerland, 295
Villi, of placenta, 206
Virgil, 90
Virginia, 360
Vision, stereoscopic, 274
"Vital index," 406
Vitalism, 95
Vitality, 348
Volcanic activity, as source of earth's water, 57
  times of, 75
  ashes, 76
Volcanism, in Formative era, 49
Volcanoes, as source of carbon dioxide, 53
Volition, 255
Volitional actions, 248
Vorgeschichte, Reallexikon der, 302
Vorgeschichtliches Jahrbuch, 302

Walcott, C. D., 69
War, and retrogressive selection, 400
  Civil, 334
  form of societal selection, 322
  World, 334
Warm blood, origin of, 112, 128, 146
Wasps, 91
Water, 249
  currents, in sponges, 239
  percentage, in body, 212
  precipitation of, 101
Water-vapor, 56, 99
  as climate regulator, 53
  in primordial atmosphere, 34, 35, 38
Waters, juvenile, 38, 76
  land, as place of chordate origin, 120
  oceanic, gathering of, 37
Waucobian period, 77
Weaklings, 336
Weapons, natural, 289
Weather, conditions, 353

Weathering, 32, 33, 81
Weaving, 295
Weevil, boll, 347
Weight, average, 217
  increase in prenatal development, 211
  of healthy persons, 347
Weismann, theory of, 219
West Indies, racial amalgamation in, 408
West Point, 356
  students at, 362
Whales, 82
Wheel, 299
Whitney, L. F., 379
Williams, H. S., 69
Wilson, E. B., 95
Winds, 55
Wodsedalek, 440
Woodward, Sir Arthur Smith, 167, 168, 177
Work, amount of, 347
  piece, in factories, 356
World, New, 277, 286, 343
  Old, 277, 278, 282, 286, 339, 343
World-code and variations, 320
World Power and Evolution, 348, 357
World War, 334
Worms, 90, 91, 114, 115
Worsaae, 275
Worship, sun, 299
Wurm glaciation, 301

X-rays, 437
  in heredity, 431

Yale Babylonian Collection, 149
Yolk sac, 191, 192
Young, C. A., 5

Zarzi, cave at, 303
  implements, 303
  industry from, 303
Zeleny, 438
"Zeros," 400
Zygote, 427

106

QH 366 .B16
Baitsell, George Alfred,
1885-
The evolution of earth and
man
25470

UNIVERSITY OF WISCONSIN
LIBRARY
Stevens Point, Wisconsin

QH366.B16
The evolution of earth and man
3 1775 141168 3